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Coal Impoundment Inspection Procedures Handbook

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CHAPTER 1 - INTRODUCTION

OVERVIEW

In order to better understand the need for coal refuse inspections and the purpose of the Mine Safety and Health Administration's coal refuse disposal regulatory program, it is helpful to briefly describe the past history of coal refuse production and disposal. Emerging from this historical context are MSHA's current efforts to regulate refuse disposal practices and its inspection training program.

While the introductory information presented here is not essential to the performance of coal refuse inspections, it is included to establish the historical justification for, and the importance of, refuse inspections and the role of the individual inspectors.

HISTORY OF COAL REFUSE ORIGINS AND DISPOSAL

Coal refuse is a waste byproduct of coal mining. It consists primarily of fragmented rock and minerals that are unavoidably removed with coal during the mining process. It also contains coal that was not separated during processing.

Prior to the early 1920s and the widespread mechanization of underground coal removal, mining was primarily limited to the thickest, most productive coal seams. These seams were mined, picked, and loaded by hand, and coal was the only material transported above ground. All the unwanted, associated waste was left in the mines.

With mine mechanization, it became possible to remove significantly larger volumes of coal and it also became profitable to mine thinner, less productive seams. However, the less exacting machine mining techniques also removed substantially larger volumes of overhead or underlying rock.

The mechanical separation of coal from its accompanying waste, initially involved only the sorting of materials. The unwanted byproduct of this process was transported to a convenient location and dumped. However, as market requirements became more stringent, mechanical separators were replaced by more sophisticated coal preparation procedures that involved not only the physical separation of waste, but also the crushing, sizing, and cleaning (washing) of the coal. Coal preparation plants thus produced a second unwanted byproduct, a slurry which is a mixture of water, and finely crushed coal and rock. This material was generally disposed of by discharging it into the nearest drainage; however, public pressure eventually caused operators to construct storage lagoons or ponds to contain the slurry. Coarse coal refuse was most often used to construct these impounding structures or 'dams'.

The specific techniques used to construct refuse dams varied with the materials and equipment at hand. There were no design standards or regulations to govern this activity. As a result, impoundment sites were usually selected on the basis of convenience and cost; few if any site preparations were made; and the refuse material was dumped from either an aerial tram or from a truck and allowed to assume its own slope angle, usually without compaction. Although the embankments were being used as dams, they were usually not designed to safely function in this role. Seepage of water through the embankment was not controlled, spillways were usually omitted or improperly constructed, adequate runoff capacity for large storms was seldom provided, and few, if any, drainage structures were built.

The slurry or liquid-fine refuse material was piped from the coal preparation plant to the impoundment where it formed a deposit of fine solids overlain with water. In many instances, as the capacity of the lagoon decreased over time, additional storage was created by placing more coarse refuse on the crest of the embankment.

The handling and disposal of coal refuse constitute an ever-increasing area of production concern. Its magnitude is related directly to the increase in the amount of coal mined, mine mechanization and the degree of coal processing. In the early 1920s when mechanical loading was first introduced in the mines, only 0.3 percent of all bituminous coal and lignite produced was automatically loaded. By 1934, this percentage had increased to 12.2 percent, and by 1970, it had grown to 97 percent.[1]

Not only has the volume of coal increased through mechanization, notably due to the increase in the number of longwall faces, but the ratio of refuse to coal has also grown substantially due to more efficient preparation plant processes and the demand for a cleaner product. Unfortunately, there have not been any official reporting requirements to provide accurate data, but projections from available numbers indicate that prior to 1940, 200 pounds of waste was left at the mine site for every ton of coal sent to the market. By 1969, the amount of waste had increased to over 400 pounds for every ton of coal sold. In 1983, a Department of Energy study determined that the majority of coal mining operations reject a full 32 percent of all material mined and processed, or approximately 900 pounds of waste is deposited at a refuse site for every ton of coal sold.

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[1] Reference presented in Appendix C: Analysis of Coal Refuse Dam Failures, Wahler and Associates, USBM, 1973.

In light of the rapid increase in the amount of coal refuse produced and the casual methods used in the past to dispose of this material, it is not surprising that many unsafe and environmentally undesirable refuse structures were produced. Periodic failures and floodings in primarily rural areas gave little indication of the magnitude or seriousness of the coal refuse problem being created.

When the Buffalo Creek flood occurred on February 26, 1972, due to a coal refuse impoundment failure, the Nation was made aware for the first time that it had an extremely dangerous coal refuse problem to resolve.

THE BUFFALO CREEK FLOOD

On February 26, 1972, one of the most destructive floods in the history of West Virginia passed through the Buffalo Creek Valley, approximately 40 miles south of Charleston. At approximately 8:00 A.M., a coal refuse impoundment on the Middle Fork tributary of Buffalo Creek failed, and approximately 140 million gallons of water and liquefied coal waste was released. This material washed out two additional coal refuse structures located a short distance downstream. The resulting 10- to 20-foot high wall of flood water swept down the Middle Fork Valley and completely destroyed the small settlement of Saunders that was located at the junction with Buffalo Creek. The flood then swept the 15-mile length of the Buffalo Creek Valley. When it entered the Guyandotte River, approximately three hours later, 118 lives had been lost, 500 homes had been destroyed, 4,000 people had been left homeless, $50 million dollars worth of property had been damaged, and $15 million dollars worth of highway damage had also occurred. Two months after the flood, seven people were still reported as missing.

In the aftermath of this disaster, a series of investigations were conducted to determine its cause (USCOE, 1972; USGS, 1972; and USBR, 1973). It was found that in the three-day period preceding the Buffalo Creek failure, approximately 3.7 inches of rain fell. This amount of precipitation occurs in this area on the average of once every two years; thus, it did not create an unusually large storm runoff. Surrounding areas of Logan County experienced relatively minor flooding equal in volume to a 10-year flood. The absence of unusual storm activity called attention to the many structural inadequacies of the failed coal refuse facility. In general, all studies agreed that this failure was due to the rapid slumping of the refuse embankment, followed by the mass movement of the remainder of the structure. These studies further identified the following reasons why failure of such a structure could occur:

- failure to prepare the foundation;
- lack of zoning and compaction in the embankment;
- lack of adequate water-control facilities, such as a spillway;
- lack of collars and baffles along overflow pipes, allowing water to move along the outside of the pipe deep within the embankment; and
- discharge of waste water from the preparation plant at the head of the pool, resulting in an accumulation of only the finest material at the face of the dam.

In light of what is known today about the Buffalo Creek flood, it is apparent that this unfortunate disaster could have been prevented through proper design, construction and periodic inspection of the refuse facility.

DEVELOPMENTS FOLLOWING BUFFALO CREEK

Following the Buffalo Creek disaster, the Mining Enforcement and Safety Administration (MESA), predecessor to the Mine Safety and Health Administration (MSHA), took action to reduce the possibility of similar coal refuse incidents. These included the following:

A. Amending and Revising Federal Regulations

An evaluation was made of the regulations then governing the disposal of coal refuse. This led to major revisions and amendments in 1975.

B. Reviewing and Approving Plans and Specifications

The revised regulations required that engineering plans for impoundments be submitted to MESA (now MSHA) for review and approval. Plans require the District Manager's approval and, in most cases, are reviewed and evaluated by MSHA's Technical Support Centers.

C. Identifying the State-of-the-Art for Refuse Disposal

Because of the relative lack of specific coal refuse technology, MESA initiated programs to determine: (1) the current (1975) status of coal refuse knowledge; (2) acceptable engineering and design practices; and (3) research needs. A major outcome of these investigations was the publication of the comprehensive, "Engineering and Design Manual for Coal Refuse Disposal Facilities." While portions of this manual now require technical updating, it remains a valuable reference.

D. Training Impoundment Inspectors

Training materials, with emphasis on recognition of signs of instability, were developed for mine inspectors, as well as for mining industry personnel.

PURPOSE AND SCOPE OF COAL REFUSE INSPECTION TRAINING

The backbone of any regulatory program is inspection. Thus, an increased emphasis on regulating the disposal of coal refuse requires that an expanded effort be made to thoroughly train mine inspectors in the fundamentals of refuse inspection and dam safety. Training sessions are conducted by MSHA to provide inspectors with enough technical and procedural knowledge to ensure that they can satisfactorily perform the following tasks:

- routinely inspect coal refuse facilities to detect any unsafe or potentially unsafe conditions that threaten either miners on mining property, or downstream occupants of flood- plain areas;

- correctly fill out inspection forms and direct this information to the appropriate MSHA personnel; and

- conduct special inspections or monitor specific work items, if requested by the District or Technical Support staffs.

The coal mine inspectors are, and will continue to be, the front-line "eyes and ears" for the mine inspection programs of MSHA. Their first-hand knowledge of, and frequent contact with the mining operations to which they are assigned, place them in a uniquely advantageous position to work with the operators.

When hazardous or unsafe conditions are detected during an inspection, these findings are reported in appropriate form to the MSHA District Manager for further evaluation. On the basis of this and possibly additional technical evaluation by the Technical Support staff and the operator's engineer, corrective actions are agreed upon for the operator to accomplish.

As noted previously, MSHA evaluates the adequacy of plans for new refuse facilities that are submitted by the operator, as well as plans for the correction of hazardous conditions on existing facilities. Operators are responsible for providing engineering supervision of the construction operation to ensure that the facility is built in accordance with the approved plan. It is emphasized, however, that mine inspectors will not be involved in, or be responsible for any of the engineering evaluations, decisions, or duties connected with constructing and repairing the refuse facilities.

ORGANIZATION AND USE OF INSPECTION HANDBOOK

This Inspection Handbook is divided as follows:

Chapter 2 - Types of refuse facilities and the hazard classification system.

Chapter 3 - Technical information pertaining to characteristics of refuse disposal facilities that could result in failure if not properly addressed during the design and construction phases.

Chapter 4 - The inspection process and the physical indications or signs of instabilitie

CHAPTER 2 - RECORDING PROCEDURES AND NOMENCLATURE

INTRODUCTION

A primary objective of the coal refuse disposal inspection program is to observe, record and report any sign of embankment instability or potential hazard. Inspections of coal refuse facilities are a part of the regular underground or surface mining inspection schedule. To effectively meet the objective, inspectors need to be familiar with the various configurations and characteristics of coal refuse facilities. This chapter introduces the Refuse Facility Identification Numbers, the Refuse Facility Classification System, and the Field Hazard Classification (FHC) System.

REFUSE FACILITY IDENTIFICATION NUMBERS

All coal refuse disposal facilities are assigned an identification number that becomes its official numerical name. This numerical name contains two types of information: (1) the type of mining responsible for creating the facility, and (2) the location of the facility.

The type of mining at a particular site is specified using the Standard Industrial Classification (SIC). The SIC classifies industrial activity by groups and assigns each group a four digit code number. Examples of the code numbers are as follows:

1111 - Anthracite Mining
1211 - Bituminous Mining

The facility location is defined by a series of numbers which follow the SIC code. First is a two letter U.S. Postal Service abbreviation for the State (see Table 1). This is immediately followed by the District number. The site numbers are assigned by the District Manager and may be the mine I.D. number. At sites with more than one separate refuse facility, individual facility numbers are added to the site number. A typical coal refuse identification number might be **1211-WV4-00036-02**, which means:

1211	**WV4**	**00036**	**02**
SIC code	State and District	Site number	2nd facility at the site

Inspectors will use these identification numbers on all of their reports and should find them helpful during field operations. Owners or operators are required to erect permanent markers next to each refuse facility as specified in 30 CFR 77.215-1 and 77.216-1. The information required on these markers includes the coal refuse facility identification number assigned by the District Manager. This practice helps to minimize identification problems during inspection activities.

Table 1
State Abbreviations
U.S. Postal Service

Alabama	AL	Montana	MT
Alaska	AK	Nebraska	NE
Arizona	AZ	Nevada	NV
Arkansas	AR	New Hampshire	NH
California	CA	New Jersey	NJ
Colorado	CO	New Mexico	NM
Connecticut	CT	New York	NY
Delaware	DE	North Carolina	NC
District of Columbia	DC	North Dakota	ND
Florida	FL	Ohio	OH
Georgia	GA	Oklahoma	OK
Hawaii	HI	Oregon	OR
Idaho	ID	Pennsylvania	PA
Illinois	IL	Puerto Rico	PR
Indiana	IN	Rhode Island	RI
Iowa	IA	South Carolina	SC
Kansas	KS	South Dakota	SD
Kentucky	KY	Tennessee	TN
Louisiana	LA	Texas	TX
Maine	ME	Utah	UT
Maryland	MD	Vermont	VT
Massachusetts	MA	Virginia	VA
Michigan	MI	Washington	WA
Minnesota	MN	West Virginia	WV
Mississippi	MS	Wisconsin	WI
Missouri	MO	Wyoming	WY

REFUSE FACILITY CLASSIFICATION SYSTEM

A. Purpose of Data Classification

When one considers that there are many hundreds of coal refuse facilities of varying types, it becomes apparent that coal refuse facility data must be collected and recorded in a systematic way. The framework for such a recording system is the Refuse Facility Classification system which is based on the facility configuration. There are many advantages for using such a system. The uniformity maximizes communication by providing a set of common, easily understood definitions for many categories of information.

B. Configuration Types

The classification system is based on the facility's configuration and is divided into eleven possible embankment types. Roman numerals I through VI are used to designate refuse facilities that do not impound water or slurry. The numerals VII through XI are used to denote various types of facilities that form, or could form an impoundment. These embankment configurations are identified in Table 2.

Table 2
Facility Configuration

Non-Impounding Embankments	Impounding Embankments
I Valley-Fill	VII Cross-Valley
II Cross-Valley	VIII Side-Hill
III Side-Hill	IX Diked
IV Ridge-Dump	X Incised
V Heaped	XI Other
VI Other	

Each of the above classifications with the exceptions of VI and XI, is described and illustrated below. Types VI and XI are to be used when a facility can not be accurately described under another type. Generally, if any single refuse facility has a combination of two or more configurations, the facility classification would be **all** of the appropriate Roman numeral descriptions, separated by commas. Thus if a sidehill facility without an impoundment is combined with a cross-valley impounding facility, the classification should read "III, VII" rather than "VI, XI." Examples of combination embankments are included in the configurations, discussed later in this section.

C. Definitions

Before a detailed discussion of the classification system can be presented, it is necessary to define a number of terms. The following definitions are of particular importance to any discussion of refuse facility types, and should be thoroughly understood before proceeding.

> **Upstream** - The uphill direction from which drainage flows.
>
> **Downstream** - The downhill direction toward which natural drainage flows.

In order to standardize references to refuse structures, these facilities will always be described as though the observer is looking downstream. Thus the left end of the embankment (referred to as the left abutment) is the contact point between the embankment and the original valley slope. It is to the left of the observer when looking **downstream.** When viewed from the downstream side, the left abutment is still the left abutment by definition, despite the fact that it is now on the observer's right side when looking **upstream.**

> **Upstream Method** - An expression describing the construction of a refuse embankment or impounding structure in which the embankment is raised by a series of lifts or layers placed on the **upstream** face of the embankment.
>
> **Downstream Method** - An expression describing the construction of a refuse embankment or impounding structure in which the embankment is raised by a series of fills placed on the **downstream** face of the structure.

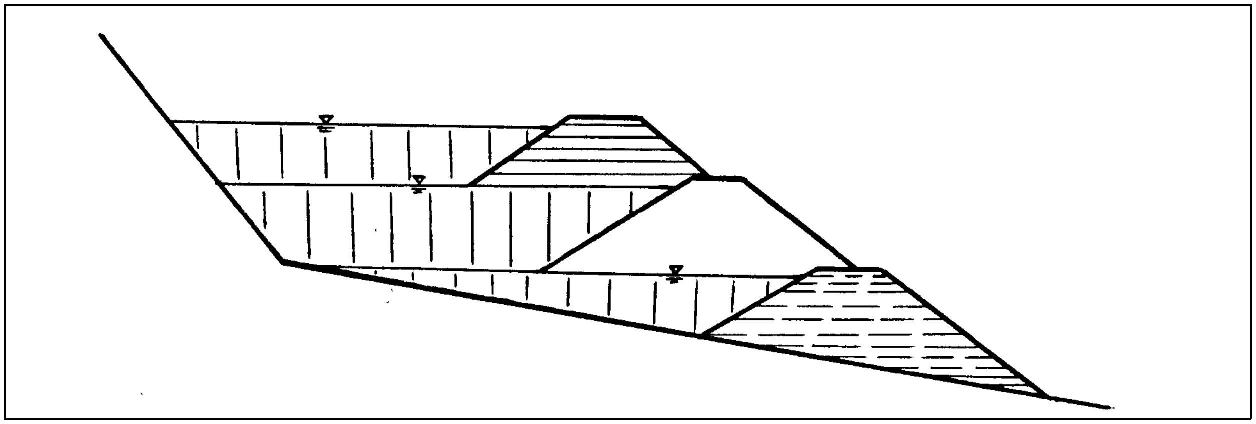

Figure 1
Upstream construction method

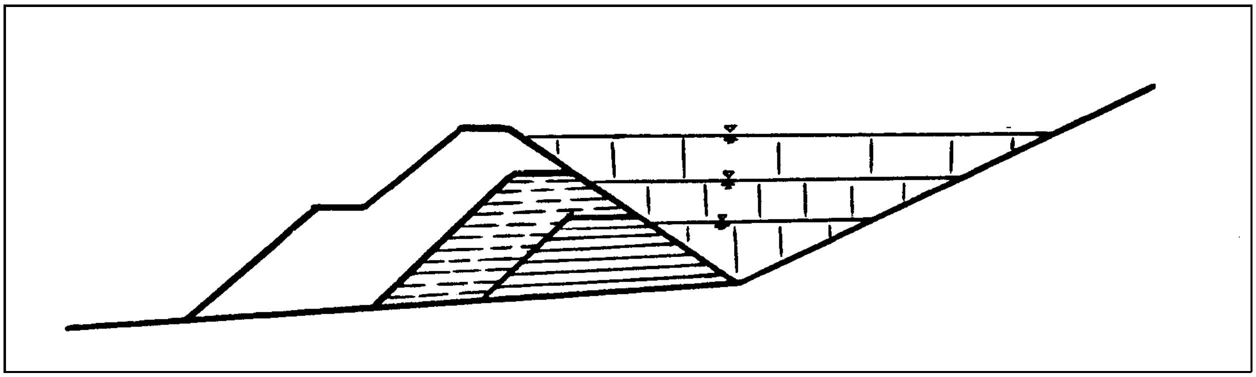

Figure 2
Downstream construction method

The upstream and downstream construction methods are illustrated in their simplest form in Figures 1 and 2 below.

D. <u>Descriptions of Facility Configurations</u>

The nine basic types of refuse disposal facility configurations are described and illustrated on the following pages. Most sites will have a simple configuration that can be adequately described using **one or more** of these basic types.

1. <u>Valley-Fill, Non-Impounding Embankment, Type I</u> -

As shown in Figure 3, the typical landfill embankment without an impoundment, completely fills a portion of a valley and has a top surface that is sloped or graded to prevent ponding. In the past, this type of embankment was often started at its upstream end and progressively extended downstream by continuous dumping

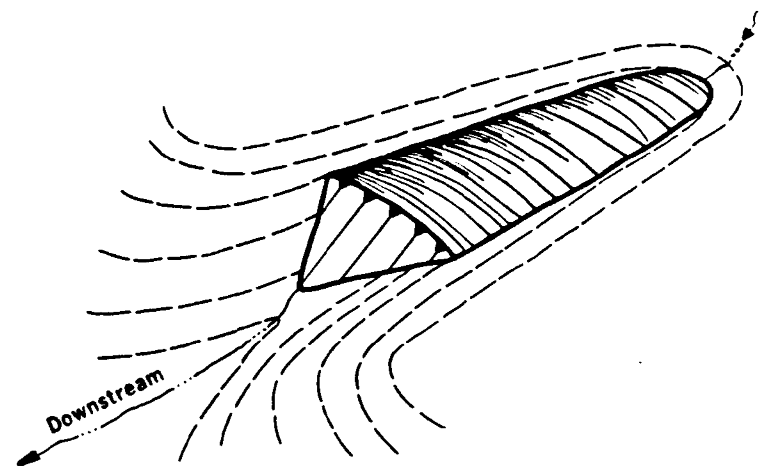

Figure 3
Type I -- Valley-Fill (non-impounding) configuration

on its downstream face. This procedure of end-dumping refuse without compaction is not an acceptable practice. Instead, the embankment is extended downstream or upstream by placing the refuse in pre-planned stages.

This same type of final configuration can also be produced by starting with a cross-valley embankment and impoundment and filling in on the upstream side. The final configuration of the facility is the same, despite the method of construction.

2. <u>Cross-Valley, Non-Impounding Embankment, Type II</u> -

A cross-valley, non-impounding embankment, shown in Figure 4, spans a valley but leaves the upstream portion of the valley unfilled. The upper end of the valley is usually kept drained through the installation of a drain pipe or culvert. These drainage structures can be designed with adequate capacity to pass peak runoffs, if intermittent ponding is not desirable. In instances where the drainage structures are not large enough to discharge peak flood flows without the temporary backup of a pond, the facility is classified as a cross-valley impounding structure (TYPE VII).

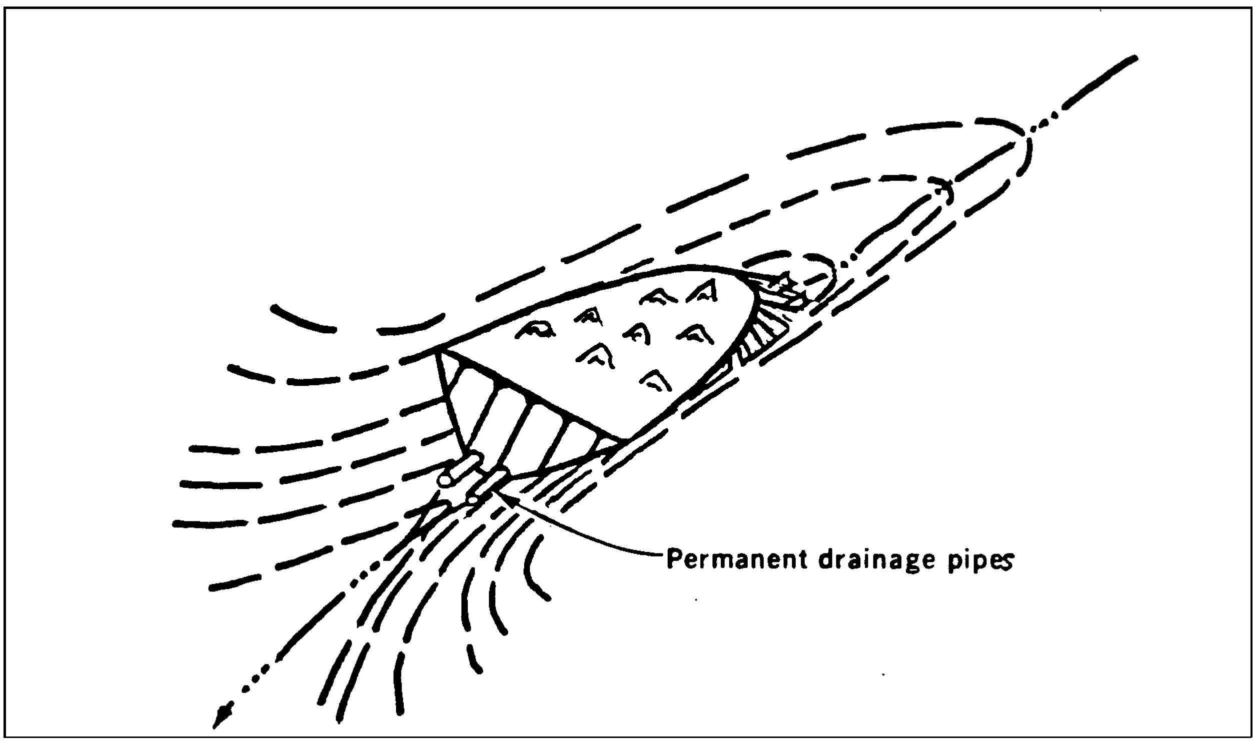

Figure 4
Type II -- Cross-Valley (non-impounding) configuration

3. <u>Side-Hill Non-Impounding Embankment, Type III</u> -

Side-Hill embankments are constructed by placing refuse material along one side of a valley without crossing the valley bottom or its stream. Figure 5 is a sketch of a typical sidehill, non-impounding refuse embankment.

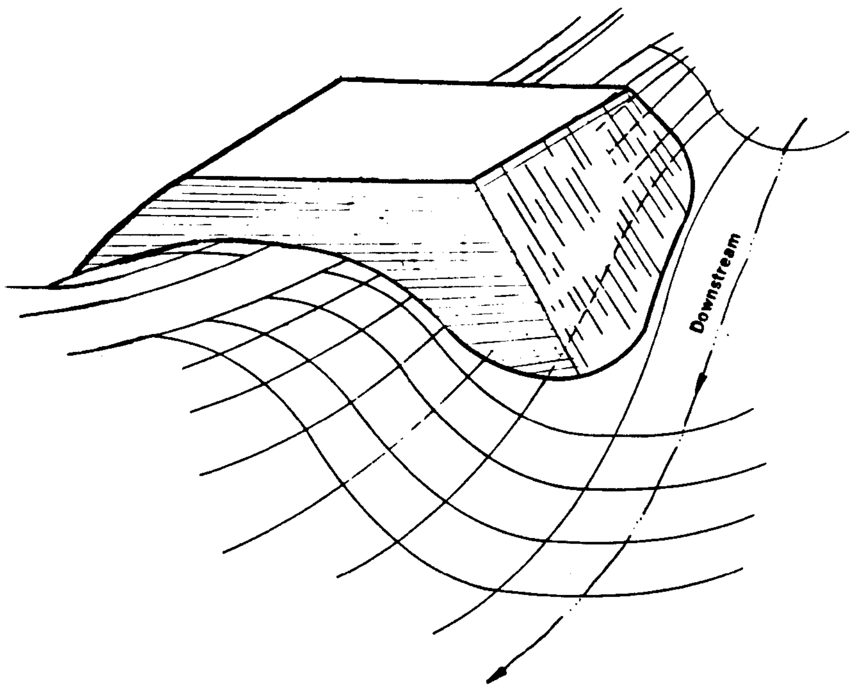

FIGURE 6
Type IV -- Ridge-Dump, extended to a Side-Hill configuration

FIGURE 5
Type III -- Side-Hill (non-impounding) configuration

As Side-Hill embankments are enlarged, a portion of these facilities is often extended across the valley floor to form a cross-valley lobe. If such a lobe is created without providing adequate drain pipes or culverts, then this portion of the facility is classified

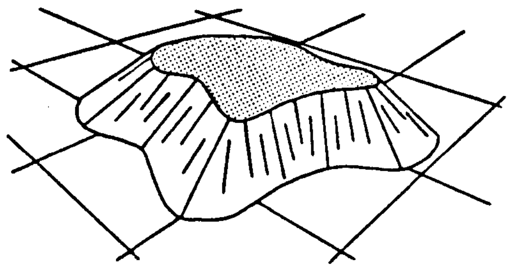

FIGURE 7
Type V -- Heaped configuration

as a cross-valley impounding structure. The appropriate type number for this compound facility then becomes III, VII.

4. Ridge-Dump, Non-Impounding Embankment, Type IV -

Shown in Figure 6, a ridge embankment occupies, and in many instances completely straddles, a portion of a ridgeline. Extensions of a ridge embankment can create a sidehill embankment on one side of the ridge line, thus producing a compound facility. The proper type classification of this compound structure would then be IV, III.

5. Heaped, Non-Impounding Embankment, Type V -

Mounds of refuse that are placed on either horizontal or moderately inclined surfaces are termed heaped embankments. Figure 7 illustrates this type of refuse disposal facility.

6. Other Non-Impounding Embankments, Type VI -

This designation is established for any refuse disposal facility that is not capable of forming an impoundment and cannot be identified by any individual or combined type designation.
The use of Type VI indicates that it must be described on an individual basis.

7. Cross-Valley, Impounding Embankment, Type VII -

As shown in Figure 8, a cross-valley impounding embankment can have a configuration that is very similar to a conventional, water-impounding dam. The embankment is most commonly constructed of coarse refuse material, but may also contain some borrow material such as soil or rock. The impoundment is normally used for the disposal of fine refuse slurry, and provides the necessary retention for solids to settle. The clarified water is then drained off.

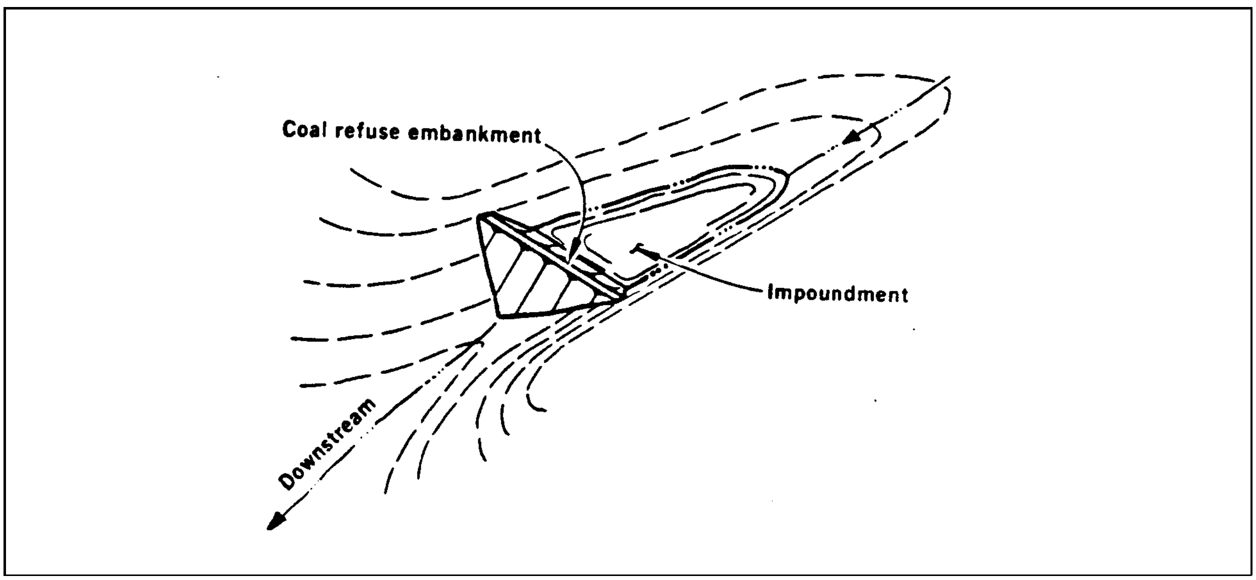

FIGURE 8
Type VII -- Cross-Valley impoundment configuration

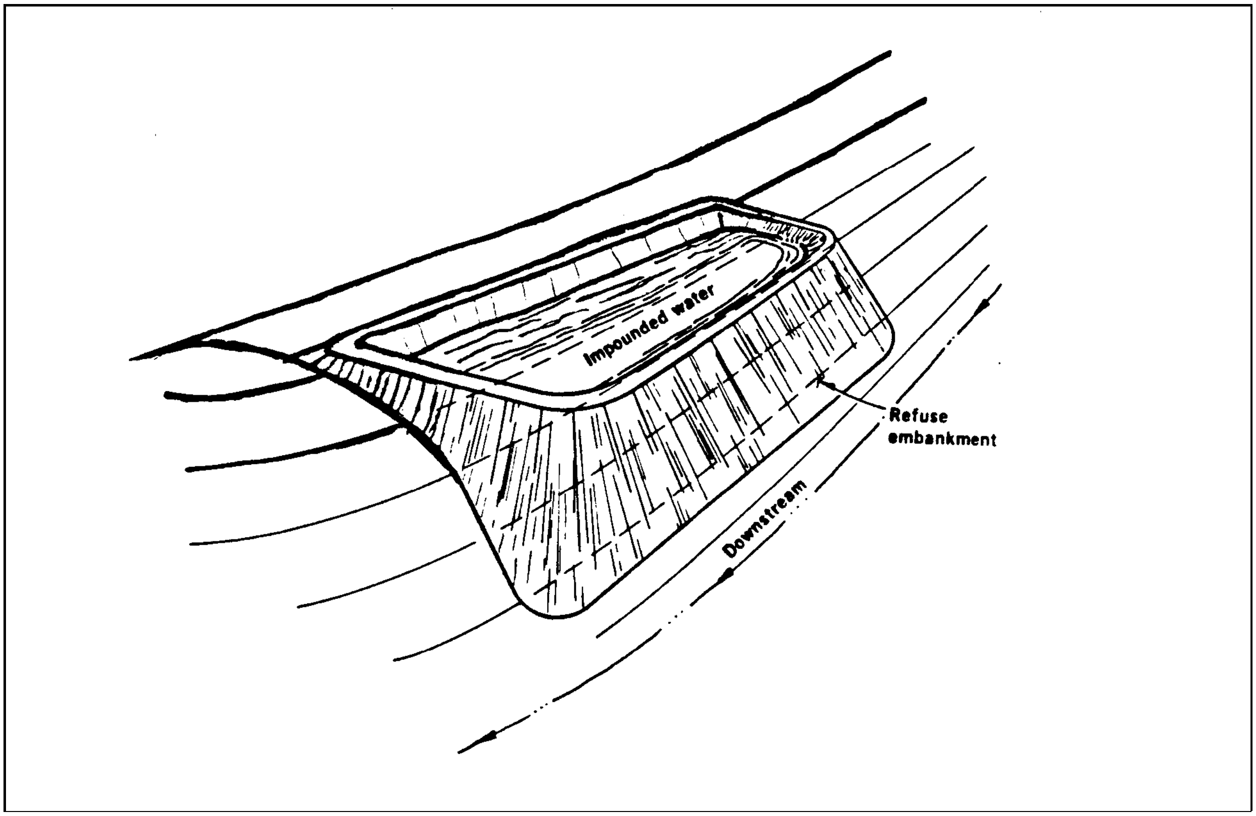

FIGURE 9
Type VIII -- Side-Hill impoundment configuration

8. Side-Hill, Impounding Embankment, Type VIII -

Figure 9 is a Side-Hill impoundment often created through diking to retain slurry or water.

9. Diked, Impounding Embankment, Type IX -

This facility is constructed on relatively flat, either horizontal or slightly inclined, surfaces by constructing a totally enclosed dike, as shown in Figure 10. These impoundments can be constructed partially below the original ground surface by using the excavated material to build the dike; or by using coarse refuse material above the original surface.

On gently sloping terrain, the dikes need not be constructed on all sides of the impoundment. The uphill slope can be used to retain one side of the impoundment.

10. Incised, Impounding Embankment, Type X -

As shown in Figure 11, an incised pond is created by excavating below the original ground surface. The excavated material is either hauled away or irregularly deposited around the periphery of the pond. If material is used to create impounding capacity of five feet or more at the upstream slope of the site (ie: above original ground through diking), then the facility ceases to be an incised impoundment and should then be reclassified.

11. Other Impounding Embankments, Type XI -

This designation is to be used for any refuse facility that is capable of impounding water but can not be readily identified by any individual type or combination of types. The use of Type XI indicates that it must be described on an individual basis.

FIELD HAZARD CLASSIFICATION SYSTEM (FHC)

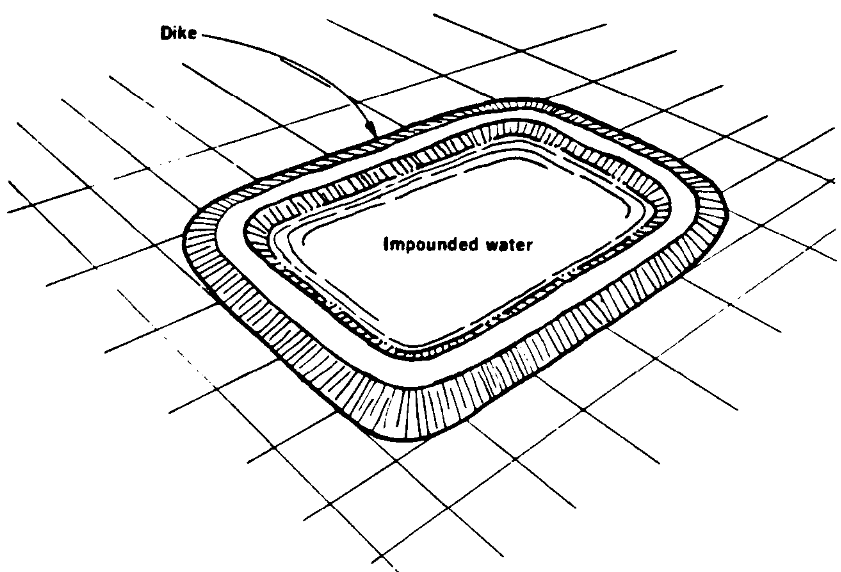

FIGURE 10
Type IX -- Diked impoundment configuration

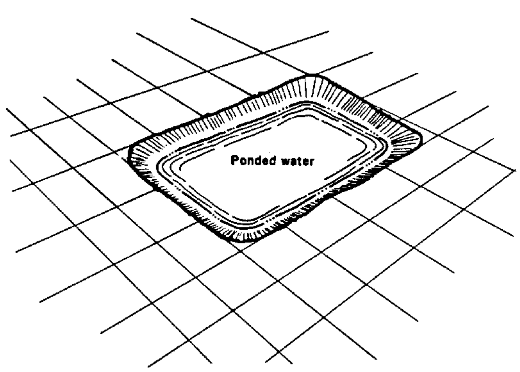

FIGURE 11
Type X -- Incised impoundment configuration

The **Field Hazard Classification** rating is based on the inspector's non-technical evaluation of site conditions. The System is based on the stability of the refuse facility or its failure probability and the consequences of such a failure. The result of a failure is based on the inspector's field observations and knowledge of downstream or downslope development. Thus, an inspector can assign the best estimate of the overall hazard potential of a site by using combinations of the following two listings:

Table 3
Field Hazard Classification (FHC)

Consequences of Failure	**Failure Probability**
I. Potential for loss of life	A. Imminent
II. High potential for injury and loss of property	B. Severe (major design deficiencies)
III. Low potential for injury and loss of property	C. Possible (significant design deficiencies)
IV. No potential for injury or loss of property	D. Possible (minor design deficiencies)
	E. None

There are 20 possible combinations using these two sets of characteristics. One of these ratings will be noted on the Periodic Inspection Form during the inspection.

Field-assigned Hazard Classification	**Description**
IA	Potential for loss of life; could fail at any time
IB	Potential for loss of life; any further degradation in stability could result in failure
IC	Potential for loss of life; possibility of failure if adverse conditions combine with deficiencies to substantially degrade stability
ID	Potential for loss of life; possibility of failure only under the most adverse condition
IE	Potential for loss of life; minimum possibility of failure

IIA	High potential for injury and loss of property; could fail at any time
IIB	High potential for injury and loss of property; any further degradation in stability could result in failure
IIC	High potential for injury and loss of property; possibility of failure if adverse conditions combine with deficiencies to substantially degrade stability
IID	High potential for injury and loss of property; possibility of failure only under the most adverse conditions
IIE	High potential for injury and loss of property; minimum possibility of failure
IIIA	Low potential for injury and loss of property; could fail at any time
IIIB	Low potential for injury and loss of property; any further degradation in stability could result in failure
IIIC	Low potential for injury and loss of property; possibility of failure if adverse conditions combine with deficiencies to substantially degrade stability
IIID	Low potential for injury and loss of property; possibility of failure only under the most adverse conditions
IIIE	Low potential for injury and loss of property; minimum possibility of failure
IVA	No potential for injury or loss of property; could fail at any time
IVB	No potential for injury or loss of property; any further degradation in stability could result in failure
IVC	No potential for injury or loss of property; possibility of failure if adverse conditions combine with deficiencies to substantially degrade stability
IVD	No potential for injury or loss of property; possibility of failure only under the most adverse conditions
IVE	No potential for injury or loss of property; minimum possibility of failure

Records of an inspection will be kept on standardized forms by the inspector. In addition to recording the Field Hazard Classification, the inspector can also express the need for additional evaluation in the comments section. If the inspector requests an additional evaluation, the basis for the request must be noted.

CHAPTER 3 - ENGINEERING CONSTRUCTION CONSIDERATIONS

INTRODUCTION

This section of the Handbook provides an introduction to the more technical considerations involved in design, construction, and the overall safety of a refuse facility. This technical discussion provides important background information that explains why certain signs of possible instability are interrelated, why certain inspection items are required, and why undesirable conditions can develop at a facility regardless of the care used in its design and construction.

The following discussion is structured in basically the same order as the inspection information presented in Chapter 4 of this Handbook. This order of presentation is intended to facilitate ready reference if the need arises during the inspection phases. However, Chapter 4 can be used independently of the following discussion.

COAL REFUSE EMBANKMENT BEHAVIOR

The following describes some of the technical factors that influence and determine coal refuse disposal practices, more specifically, the engineering behavior of refuse embankments. Inspectors are not expected to master the technical information; however, its presentation should provide a basis for a better understanding of the inspection requirements discussed in Chapter 4. Those inspectors wishing to pursue the more technical aspects of coal refuse engineering and design are referred to the **Engineering and Design Manual: Coal Refuse Disposal Facilities** (MESA, 1975). The publication, although no longer in print, is available through the National Technical Informational Services and other sources.

A. General Area Conditions

A number of critical general area conditions of a refuse disposal site are fundamental to designing a refuse facility. These include downstream or downslope conditions that would be affected in the event of a facility failure, and upstream or upslope conditions that determine the watershed or runoff characteristics of the planned facility. Both of these designs are discussed in the following paragraphs.

1. Downstream or Downslope Conditions -

Generally, the magnitude of potential impact on the downstream or downslope areas in the event of facility failure, is a function of whether or not the refuse facility has an impoundment. The failure of a non-impounding refuse embankment would normally have a relatively limited physical area of impact, within approximately several hundred feet of the embankment.

This is not to suggest that "dry" refuse dumps can not be extremely dangerous under the right circumstances. As an example, if a proposed non-impounding facility will have its embankment slope immediately above a mine opening or a preparation plant, then the failure of this embankment could have a significant detrimental impact on these developments. The Aberfan, South Wales, disaster of October 21, 1966, that partially covered a school, is one such tragic occurrence.

At the other extreme, a small impounding facility may be planned immediately uphill from a very large stream or river, with no adjacent population or development. In this case, failure of the facility with a release of the stored water and portions of the fine refuse would not threaten property or life, but could possibly be a significant environmental issue. Proper consideration must be given to the potential threat to lives and property by evaluating both the downstream development and the magnitude of the liquid material that would be released in the event of a failure.

2. Upstream or Upslope Conditions -

The size and characteristics of the watershed above a proposed refuse facility determine the amount of storm runoff and thereby dictate design parameters of proposed downstream refuse facilities. Runoff characteristics are most critical for impounding facilities; however, they can also influence the placement of a non-impounding facility, particularly if it is located in a natural valley.

If for example, the majority of the watershed is wooded, storm runoff would be much smaller than a similar area intensively developed with large roof or asphalt areas. The reason for this difference is that a wooded area intercepts rainfall with its vegetation and allows it to infiltrate into the soil, while a paved area sheds rainfall quite rapidly. A watershed primarily used for agricultural purposes produces a storm runoff somewhere between these two watershed extremes.

A careful assessment of the watershed of a proposed refuse facility is one of the initial steps in the design process. In the instance of impounding facilities, an adequate combination of storage capacity and discharge capability must be provided in accordance with runoff requirements. Failure to adequately provide these items, could result in failure of the embankment during a very large storm. The design of a non-impounding embankment must also include diversion ditches and/or discharge channels with proper consideration of storm runoff to avoid severe erosion that could result in failure of portions of the embankment.

The design of all embankments located near streams must encompass the storm conditions of these waterways. Failure to plan for floodway requirements can result in erosion of the toe of the slope, embankment failure, and possibly the temporary creation of a dam, further increasing the potential for downstream flooding.

B. Construction and Site Conditions

A designer should attempt to locate a refuse facility on a site that will minimize construction difficulties. However, due to constraints such as access, land availability and transportation costs to the disposal area, designers frequently must use sites that have less than optimum characteristics.

Regardless of the number or severity of design constraints, there is a safe and structurally acceptable engineering solution for most potential refuse sites, if given adequate engineering investigation. However, the more site constraints, the more costly the design solution and the construction phase will be. The designer must therefore optimize the relationship between these costly

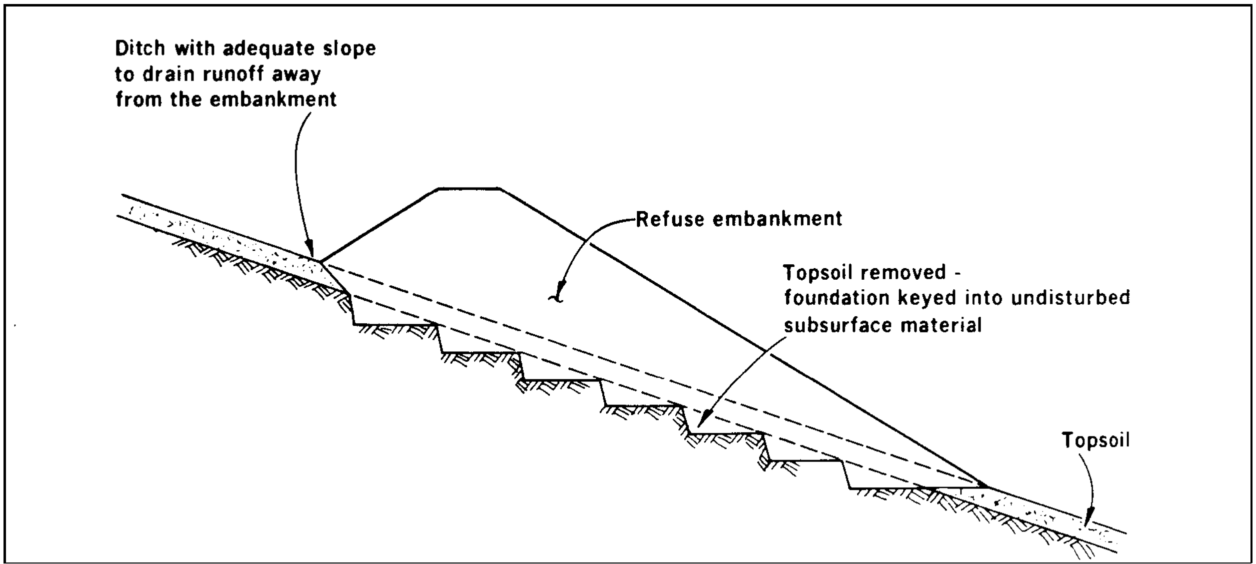

FIGURE 12
Benched foundation on steeply sloping hillside

constraints and the savings resulting from efficient mine operation. The following paragraphs identify and discuss a number of the more common site problems that are often encountered by a refuse site designer. The more common structural means of minimizing these problems are also discussed.

1. <u>Topography</u> -

An inclined or steeply pitched refuse disposal site normally requires a greater degree of engineering investigation than flatter disposal sites. Facility construction on a sloped site is also more complex and difficult. These difficulties stem from a number of factors.

Foundation preparation is normally more involved on steep embankment sites. In many instances, it is necessary to "bench" or "key" the foundation into the natural hillside to prevent the sliding that could otherwise occur at the interface of the embankment and the natural hillside. This type of foundation construction is shown in Figure 12. Benching is not always appropriate however, and must be determined by the designer on a site specific basis. The inspector should examine the approved construction drawings to ascertain the designer's intent.

A second major design and construction concern resulting from steep terrain is the construction of required drainage facilities such as diversion ditches and spillways. These structures often must be placed or 'cut into' undisturbed hillside slopes, a task that could be quite challenging and difficult to maintain, particularly on steep sites. Slippage and sliding of upslope materials during periods of heavy rainfall must be avoided through special construction provisions. The failure to provide this protection may result in blockages of these structures at the time that they are most critically needed to pass storm runoff. Depending on the natural slope gradients above drainage structures and access roads, it is often necessary to bench, regrade, and plant these critically steep areas.

Constructing a refuse disposal facility on a relatively flat site normally involves fewer topographic constraints. If adequate space is available, a refuse structure will be located away from a stream channel above the floodplain. This greatly lessens the need for diversion ditches, spillways, and other drainage structures. Similarly, if the option exists, a designer will locate the proposed facility in an area with minimal foundation problems (i.e., on a gently sloping site with good soils), thus minimizing preparation costs.

One design constraint that is unrelated to stability, but is critical to the ultimate use of the disposal site, is the need to contour the configuration of the final refuse structure to better fit land use needs. This concern can be a significant design factor on level sites, while it is usually less critical in steeper terrain situations.

2. Foundation Preparation -

Proper preparation of the foundation area of a coal refuse facility is critical to the future stability and long-term characteristics of the embankment. Failure to initially plan and construct a stable embankment base could cause the structure to eventually fail. The work involved in preparing the foundation area generally falls into five types of activity which are discussed in the following paragraphs:

- removal or clearing of vegetation or other undesirable materials from the foundation area;

- measures required due to steep topography;

- removing soft or otherwise unstable subsurface materials;

- measures required to provide adequate subsurface drainage; and

- measures to reduce or minimize seepage from an impoundment.

Fundamental to **all** foundation construction work is the removal of vegetation and topsoil, not only from the embankment area, but also from that area that may eventually be covered with an impoundment. The removal of vegetation is essential for a number of reasons. If included in the refuse embankment, it may ignite and thereby ignite the refuse material. The decomposition of buried roots or tree trunks can also create lineal voids in the embankment that provide convenient routes for oxygen access and through-embankment seepage. Topsoil **must** be removed because of its poor structural properties and its high organic content. Once the foundation area is stripped of vegetation and topsoil, pockets or extensive areas of structurally poor or soft subsurface materials could be exposed. Depending on the specific conditions at hand, these materials must be either removed through excavation or specially compacted. In any case, such conditions must be alleviated prior to initiating embankment construction.

As noted in the preceding section, special foundation construction measures are necessary on disposal sites that are steeply sloping. Failure to adequately bond embankment material to a sloping base can cause future downslope movements and eventual failure.

Because of current or future drainage requirements, special layers of drainage materials may be required in the embankment, at the embankment/foundation interface, in the foundation, or at the abutment contact. As an example, drainage blankets are often installed to assure that any through-embankment seepage is collected and discharged in a controlled manner to reduce water pressure buildup to prevent piping at the downstream face, and to provide a common discharge point for the drainage treatment.

Figure 13 is a drawing of a typical drainage blanket installation beneath the downstream portion of a refuse embankment. The phreatic surface shown is purely conceptual and can vary significantly with permeability and drain capacity. The materials used in constructing the drainage blanket normally consist of graded sand or a graded sand-gravel mixture with little or no fine particles. Acceptable drainage blanket materials are usually designated between well graded sand and well graded gravel depending on the actual site conditions. The drainage materials vary with each site and depend upon the grain size and characteristics of the coarse refuse placed above, and the grain size and characteristics of the natural foundation material under the drainage blanket. The drainage material must be hard, strong, durable and resistant to acid attack. It must also be sized to drain, yet prevent the migration of refuse or foundation soil particles into and possibly through the drainage material. In some instances, additional granular transition zones may be required to meet explicit filter design criteria. This can also be accomplished with geotextile material by supplying adequate design documentation. To ensure that drains continue to function properly, their performance is normally monitored with piezometers.

In some instances where a natural spring is located within the foundation area, a different type of drainage collector system is often installed. One such example is depicted in Figure 14 where successive layers of differing drainage materials are placed over the collector area or rock drain which directs the spring flow to the main collection zone beneath the embankment, or to the toe of

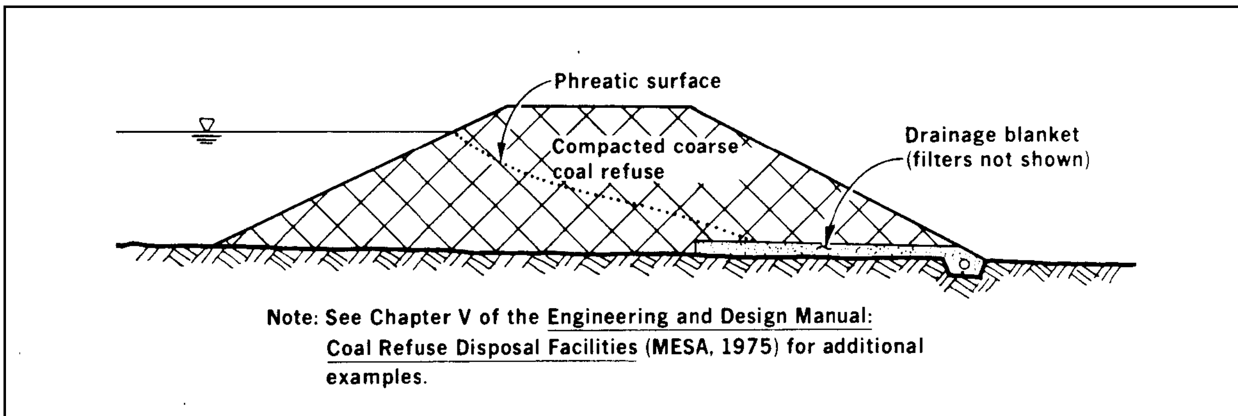

FIGURE 13
Horizontal blanket drain

the embankment where it is discharged. The intent of this type of drainage collector is to prevent spring flow from entering the coarse refuse material.

The final type of major foundation work is the prevention of seepage into and through leaky foundation materials. When possible, the designer will normally avoid locating an impounding embankment at a site where such foundation improvement work is required. When this is not possible, two techniques for reducing seepage can be implemented. The first method, which is very costly, is to infuse or grout the foundation materials by injecting a cement slurry (or other similar material) into the material voids of the foundation. Due to the

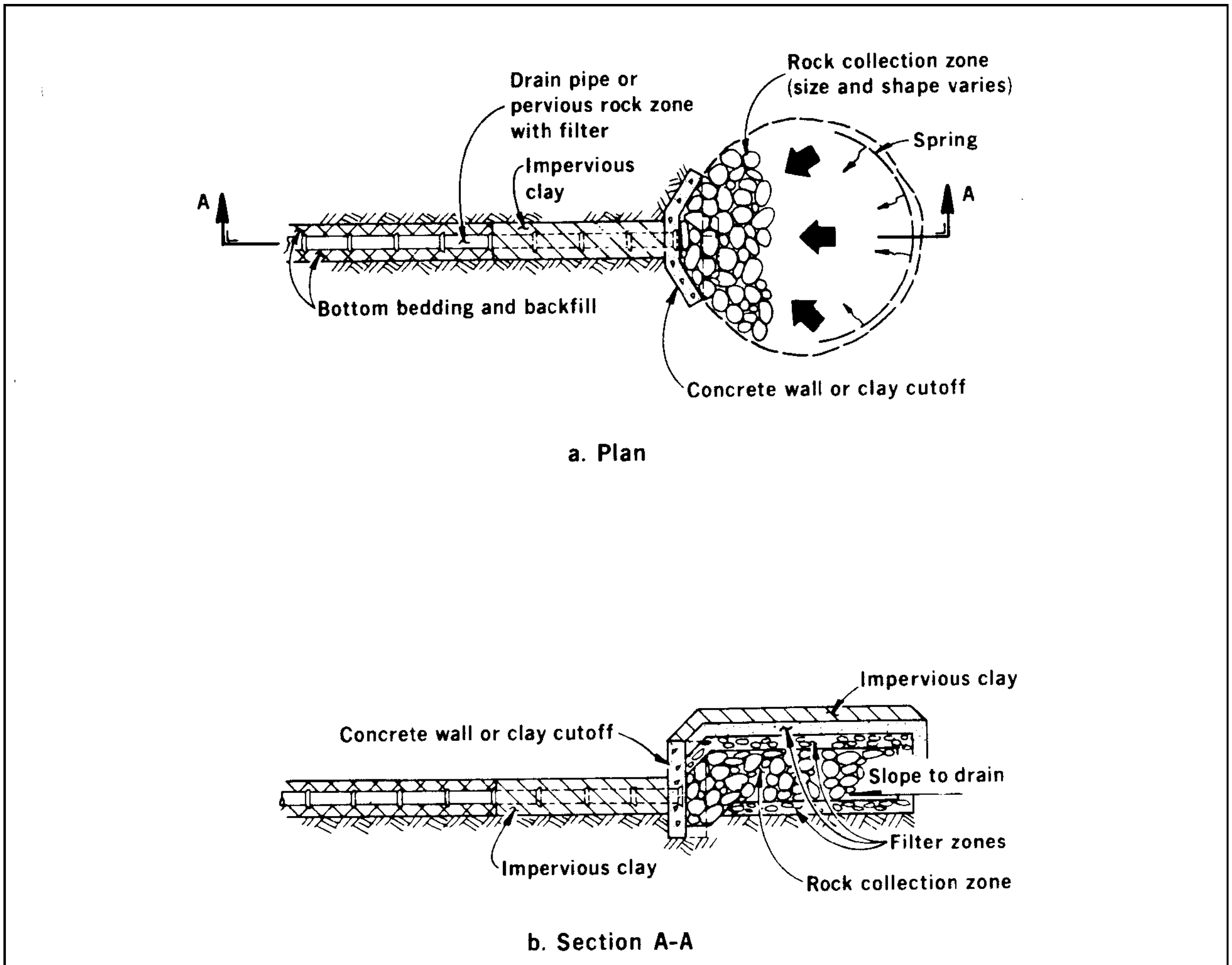

FIGURE 14
Spring collection drain

high cost of providing a grout cutoff, this procedure is seldom used on a coal refuse facility. A less costly alternative is the construction of an impervious blanket of fine soil over a portion of the impoundment area, upstream from the embankment. The placement of several feet of a clay-type soil over the leaky foundation material will not totally eliminate seepage, but it will minimize it.

3. Material Characteristics -

Coarse coal refuse and fine coal refuse are the two types of waste materials that are routinely produced by the coal mining process, and it is these materials that a designer must provide for and use in the construction of most refuse disposal facilities. Other materials are also included in refuse embankments, but this use is less extensive and stems either from the need to:

- dispose of extraneous material, or

- provide some special embankment feature such as a drainage blanket, impervious blanket, or to protect the refuse from water runoff erosion. Each of these categories of materials is discussed below.

Coarse refuse is the solid waste material that is separated from the coal and liquid fines in the preparation plant. Because of its nonliquid state, it can be readily transported to the embankment site either by wheeled vehicles, conveyors and/or continuous trams. Coarse refuse consists primarily of fragments of shale, siltstone, and claystone rock (with lesser amounts of sandstone and limestone), and generally has structural properties well suited for the construction of a stable embankment. However, the specific characteristics of the coarse refuse materials at each disposal site are dependent upon the coal seam being mined, the mining methods used, the type and efficiency of the coal preparation plant, and the water content of the refuse at the time of its placement.

In some instances, the coarse refuse is rather large grained, varying in size from coarse sand and gravel to small cobbles, three to five inches in diameter. When reasonably dry, this type of refuse material can be used to construct a very dense structural fill. At the other extreme, some coarse refuse material is relatively fine-grained, with a large percentage being within the silt range and having maximum size of small gravel. When dry, the smaller coarse refuse can also be effectively and efficiently used for structural fill. However, when wet (as is often the case with some preparation processes), this material must be spread out at the disposal site and allowed to dry before adequate compaction can be obtained. Because of the variation in coarse refuse characteristics, a designer must become familiar with the particular mining operation and the properties of its refuse prior to engineering a disposal facility. It is important to differentiate between portions of an embankment that are most important to its stability and those portions of an embankment that are less important to stability. Coal refuse disposed in critical structural portions of the facility is referred to as "constructed" or "structural fill" refuse. In the structurally less important portions of the facility, construction control is less critical and the disposed refuse is referred to as "placed" or "nonstructural" refuse.

Fine refuse material is hydraulically separated from the coal during its processing. It is therefore much finer than coarse refuse (i.e: particle size varies from clay or very fine silt to fine sands). These fines are suspended in a water solution or slurry, and are extremely difficult to handle unless pumped through a pipeline. Most available dewatering systems, including clarifiers, filters, and centrifuges do not remove enough water to permit its being handled as a solid. Thus, it can not be separated and compacted like the larger solid refuse.

It is sometimes possible to overcome handling problems by combining dewatered fine refuse with coarse refuse to create a combined refuse. If the coarse refuse is large grained and dry enough, the resulting combined material can quite effectively be used for structural fill purposes. However, mixing materials containing too much water will only result in the creation of a combined refuse that is too soft for structural purposes that will require extensive field drying before it can be used. In these instances, the designer must be careful that this material is not used in a portion of the embankment that is structurally critical or, if used, its area of placement is large enough to facilitate drying and subsequent compaction during a period of favorable weather.

Because of the handling difficulties, the semi-solid fine refuse is often disposed behind a coarse refuse impounding embankment. It is transported to the impoundment by way of a pipeline and discharged near the upstream face of the embankment. If properly discharged in this manner, the more coarse particles will settle immediately and force the liquid portion of the slurry to flow upstream away from the embankment. Thus, embankment infiltration and seepage are discouraged.

As mentioned above, a designer will often use additional types of materials for embankment construction to accomplish a particular purpose. One of the more common of these is to provide drainage collection zones in critical embankment locations. The normal grain size for this material is sand to sandy gravel. Even if available refuse material has a similar grain size, such material is not suited for drainage collection zone purposes, because the individual siltstone, shale and claystone particles break down over various periods of time. Suitable drainage materials must there-fore be obtained either from local sand and gravel suppliers, or from a nearby borrow area or river bottom where sand and gravel are available in the size required.

Impervious materials are often used within an embankment to construct relatively impermeable barriers, either in the core of the structure or as a blanket in the upstream impoundment area, as discussed above. While often termed clays, these impervious materials can vary from silt size, with just enough clay to hold it together, to very "fat" clays with very little silt. Both types of materials form acceptable impervious layers, provided they are properly placed and are continuous. If too wet, both materials are extremely difficult to work with using normal construction equipment. Thus, considerable care must be taken in selecting impervious borrow materials and placing them during periods of favorable weather.

Various types of rock materials are also incorporated into a refuse embankment as a mining by-product. Rock materials may be derived from excavating new mine openings or from stripping operations. In both instances, the matching of intended use with the structural properties of a particular rock is imperative. Thus, hard, competent sandstones and limestones are suited for some embankment purposes where less durable rocks, such as shale, siltstones, and claystones, would be totally inadequate.

Hard sandstone is usually very resistant to weathering and deterioration, and is therefore suited for some drainage structure uses, which include embankment slope riprap, channel protection, and as initial starter toes for embankment slopes. While hard limestone has similar structural characteristics, special care must be taken to avoid using this type of rock where acid drainage or seepage is present and the item can not be readily repaired. The chemical reactivity of limestone in the presence of acid results in its deterioration over time. This is also true for calcareous sandstones. The softer rock materials (i.e: shales, siltstones, claystones) can be used as structural fills within an embankment, if properly placed and compacted.

Rock riprap should be hard, strong and durable with no thin elongated pieces. The material should be blocky, well graded, and placed to the thickness stated in the design specifications. Furthermore, all interstices should be filled to provide a smooth appearance. Regardless of the rock type being used, care must be taken to avoid indiscriminately mixing it with coal refuse in such a way as to create air pockets or small voids in the embankment. Such internal passageways provide oxygen with ready access to the ignitable refuse materials and spontaneous combustion can occur. This is particularly critical if mine excavation rock is haphazardly dumped on a non-impounding embankment without mixing it with the refuse material and compacting it after it is in place.

4. Materials Handling -

One of the major criteria in the design and construction of a refuse disposal facility is the optimization of all aspects of materials handling within the mining operation. These activities include the transportation of the mined material to the preparation plant, the preparation process itself, the transportation of the refuse material to the disposal site, its handling at the site, and the related economic, safety and equipment considerations inherent in each of these activities. While the embankment designer normally has little control over the mining or preparation plant activities, one must be familiar with them to economically and efficiently integrate disposal activities with the overall operation of the mine.

The nature, duration and complexity of the mining and processing operations will largely determine not only the configuration and design of the refuse facility, but also the amount and sophisti- cation of available refuse handling equipment. Thus, in some large mining operations, equipment such as end-dump trucks, bottom-dump trucks, and single and double engine scrapers may all be available and economical for use in moving the refuse.

In other instances, only one or two of these hauling units will be required, working only one or two shifts per day. As the distance or height from the preparation plant to the disposal area in- creases, the use of a conveyor or continuous tram system in con- junction with the basic hauling units can become more attractive. Thus, during the planning and design phase of the refuse disposal operation, a designer must carefully consider all the equipment or transport options that will be available to move the refuse from the preparation plant to the disposal site.

The second element of materials handling involves the on-site handling or placement of the refuse material. The embankment design, particularly the structural fill portion, is contingent upon certain types of equipment being available to properly place and compact the materials. The type of equipment needed will be determined by the amount and characteristics of the refuse, as well as by such specific construction needs as compaction.

If, as an example, the refuse material has relatively good characteristics, it may be possible to use only scrapers to both spread and compact the material. However, in other instances trucks may be required to roughly position the refuse, with subsequent spreading and compacting being accomplished with a bulldozer. Each of the above materials handling options must be evaluated prior to beginning construction of the embankment. They should be continuously reevaluated throughout the life of the disposal operation.

5. <u>Placement and Compaction</u> -

A proper embankment design that assures optimum safety and future stability, is only as good as construction performance. Of particular importance is the day-to-day placement and compaction of the refuse materials. This means a specific location, a speci-fied thickness and adequate compaction.

Structural elements of the embankment must be in conformance with the design of the facility, with each placed in its specified location at the required thickness, and compacted to the extent designated by the design specifications. Failure to properly implement these two design essentials can result in undesirable future embankment conditions, which may include burning, hazardous slide conditions, unanticipated through-embankment seepage, acid formation and many other types of instabilities.

Compaction needs are most frequently specified in terms of the minimum acceptable density allowed to obtain the required structural properties of the material. In the first stage of embankment development, construction is normally slow enough to permit the use of haulage equipment to compact the refuse. This is preferred to part-time usage of costly compacting equipment. Specialized equipment might include a variety of available compactors, including rubber-tired, segmented pads, sheepsfoot, spike, grid, and vibratory rollers.

6. <u>General Construction Practices</u> -

Without proper controls, a good refuse embankment design is of little value. An operator's overall approach to embankment construction will determine whether an acceptable and safe refuse facility is built. A haphazard method of operation is apparent not only in the day-to-day construction activities, but also during particularly critical phases of construction when a conscientious effort must be made to quickly and efficiently carry out the plan requirements. Examples of these activities include:

- the installation of pipes requiring special bedding and the careful compaction of adjacent materials;

- the installation of sand and gravel drainage zone materials that must be placed in a continuous manner and properly tied to the drainage discharge system;

- the construction of impervious clay cores or blankets that are needed to restrict through-embankment seepage;

- the construction of spillway channels to a predetermined geometrical shape to satisfy the hydraulic requirements;

- overall site and foundation preparation activities; and

- hydraulic (slurry) filling patterns.

Each of the above construction operations requires a degree of on-site planning and organization not normally required in the routine, day-to-day construction schedule.

An operator's failure to properly plan or otherwise provide for special construction needs normally results in improper or hazardous installations. Poor construction planning is most often evidenced by such things as:

- Lack of having adequate personnel or equipment on hand to complete a task without undue and sometimes dangerous delays;

- having the wrong types of equipment or improperly maintained equipment when other or better equipment is needed;

- the failure to provide for routine refuse disposal while special construction activity is being carried out; and

- providing either inadequate or incompetent supervision, thus delaying the progress of work and possibly creating hazardous embankment conditions.

C. Embankment Slopes

Slope stability[2] is one of the most critical elements of refuse embankment design and construction. The discussions in this chapter provide an introduction to the concept of slope stability and also describe how stability is affected by factors such as material characteristics, seepage, and erosion.

1. Introduction to Slope Stability -

Various factors can have a major influence on the stability of an embankment. These include, but are not limited to, the following:

- the types of materials used in the embankment, their method of placement, and their location;

- the condition of the embankment foundation, its materials, and configuration;

- the slope and height of the embankment faces; and

- the presence and location of water either in or adjacent to the refuse embankment.

While the stability of both new and older refuse facilities is influenced by these factors, it is considerably more difficult to determine what adverse conditions are at work in older refuse structures. When designing a new facility, an engineer minimizes the chances for developing instability by:

- controlling the materials used in construction and their placement;

- pre-determining and specifying a safe facility configuration and acceptable slope angle;

- specifying the proper preparation of the foundation area; and

- providing adequate drainage facilities to minimize future surface water and seepage problems.

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[2] For clarity, this stability discussion is limited to embankment slopes as opposed to excavated slopes into natural soils or rock. It is noted , however, that the mechanics that determine stability are identical for both types of slopes. The reader is referred to Chapter V of the **Engineering and Design Manual: Coal Refuse Disposal Facilities** (MESA 1975) for a more detailed discussion of slope mechanics.
When confronting instability in an older, non-engineered embankment, an engineer has only limited knowledge about the embankment's construction history and its internal conditions.
This situation is often encountered when an operator proposes to transform an idle, pre-Federal Mine Safety and Health Act refuse site into a modern impounding structure. Even post-Act refuse embankments constructed in two-foot lifts may be unacceptable dams. Thus, without an exhaustive field exploration and series of exploratory tests, the engineer is not able to evaluate the stability of the embankment and to recommend appropriate remedial improvements. In such instances, the engineer can either conduct an extensive investigation and analysis required to determine existing embankment conditions, or use a more conservative embankment configuration in order to ensure future stability.

2. <u>The Mechanics of Slope Stability</u> -

There are basically two types of forces that must be considered in evaluating embankment stability. These are the forces tending to produce movement (or instability), and those tending to resist movement. When these forces are in balance, a stable condition exists and no movement occurs. When the available resisting forces are greater than those tending to produce movement, there is a margin of safety against instability that is referred to as the Factor of Safety.

The simplest example of the mechanics of embankment stability occurs when there is no seeping water from the slope being analyzed. This condition most often occurs at a non-impounding embankment where an internal drainage collection system is normally provided to ensure that groundwater and surface water do not enter the embankment materials. If stability or embankment movement becomes a problem in this setting, it can vary in size, shape, and depth. To isolate the complex mechanisms that determine the extent and location of this movement, engineers use three simplified conditions of analysis:

- slippage along a circular arc,

- wedge-shaped slippage, or

- a combination of these two.

The combined form of movement is by far the most common and is also the most difficult to analyze and describe. Thus, for the purposes of this discussion, only the first two types of failure modes are described.

The circular arc failure is the more common movement shown in Figure 15. As illustrated, movement occurs along a circular arc, about an imaginary center point of that arc (center of rotation). The materials simply rotate down and 'out' from their previous location. The lower portion of the failure can form a bulge on either the embankment slope or downslope from its toe. The upper portion of the failure zone settles or slumps, causing a vertical displacement or scarp to appear on the slope or along the down-stream edge of the embankment crest.

A wedge failure, shown in Figure 16, normally occurs where the presence of a soft layer of material, either within the embankment or its foundation, encourages a

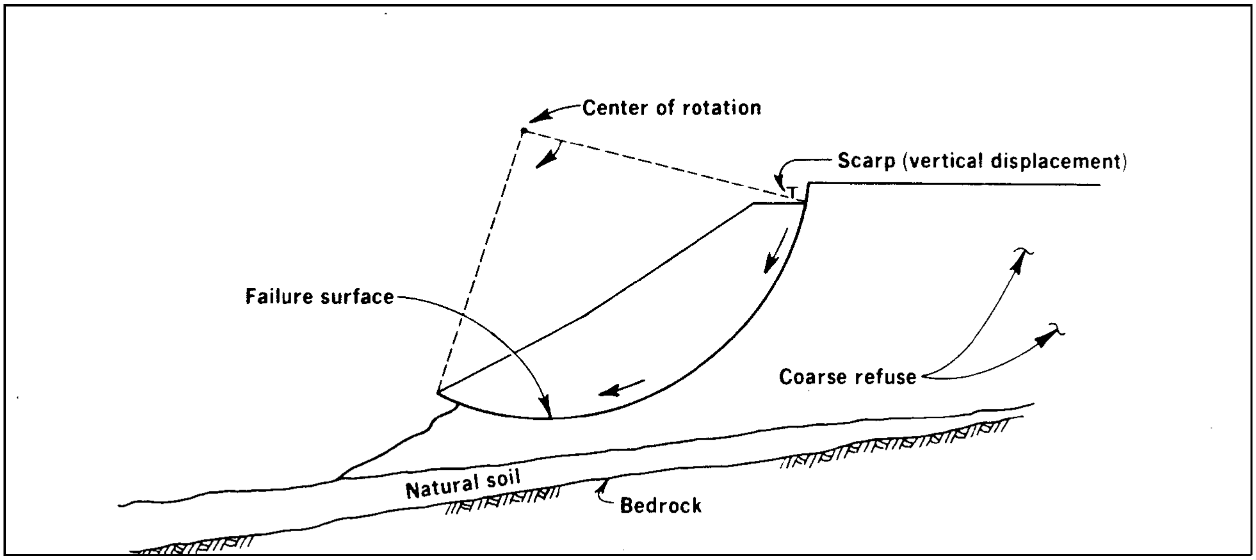


FIGURE 15
Circular arc failure in homogeneous material

lateral shifting of a portion of the slope. This type of movement also results in bulging at or near the toe of the failure zone and settling at or near the embankment's crest. Thus, the dynamics causing the movement can not be determined by observation alone.

It should be understood that both of these failures usually do not cause an abrupt and massive movement of material. More often, they develop slowly over an extended period of time. However, once the initial movement has occurred, the remaining portions of the embankment become less stable and movement progresses

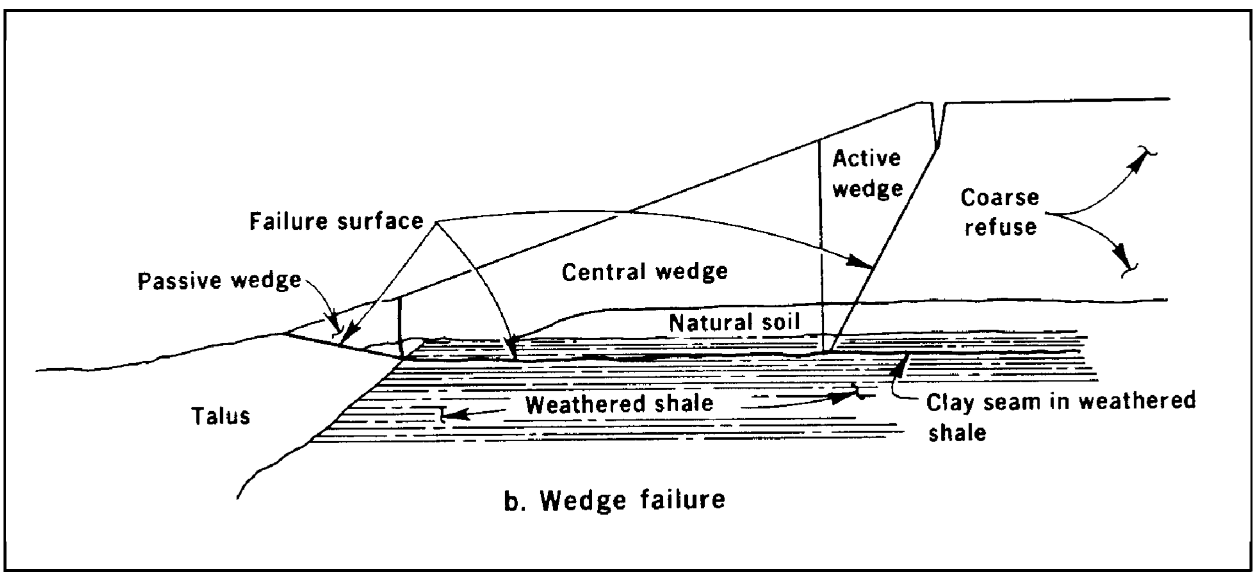


FIGURE 16
Examples of slope failures

further into the embankment. The further this zone of movement penetrates, the greater the likelihood of abrupt catastrophic failures.

As can be noted in the instance of the circular arc failure, shown in Figure 17, the principal downward force acting on the circular segment is caused by the weight of the segment itself (W). The principal counteracting force is the supporting or normal force (N), provided by the remainder of the embankment, perpendicular to the failure surface. Because the direction of N is perpendicular to the failure surface (through the center of its arc) and not directly opposing W, a resultant force (T) remains which tends to "swing" the circular segment down and "out", around the point of rotation (P). In the absence of resisting forces, the circular segment would freely swing downward and out until its center of gravity was directly beneath P. However, this pivotal movement is resisted by the cohesive and frictional strength of the refuse material, along the outer edge of the failure surface.

This resistance to lateral or shearing movement is termed shear strength, and its magnitude is shown as (F). If F is equal to or greater than the rotating or slipping force T, which is tending to move the circular segment around P, then there will be no embank-ment movement. However, if the shear strength of the refuse material is less than the movement force, a circular arc failure will occur. The degree of stability of an embankment, or its Factor of Safety against failure, can be mathematically stated as follows:

Resisting Forces

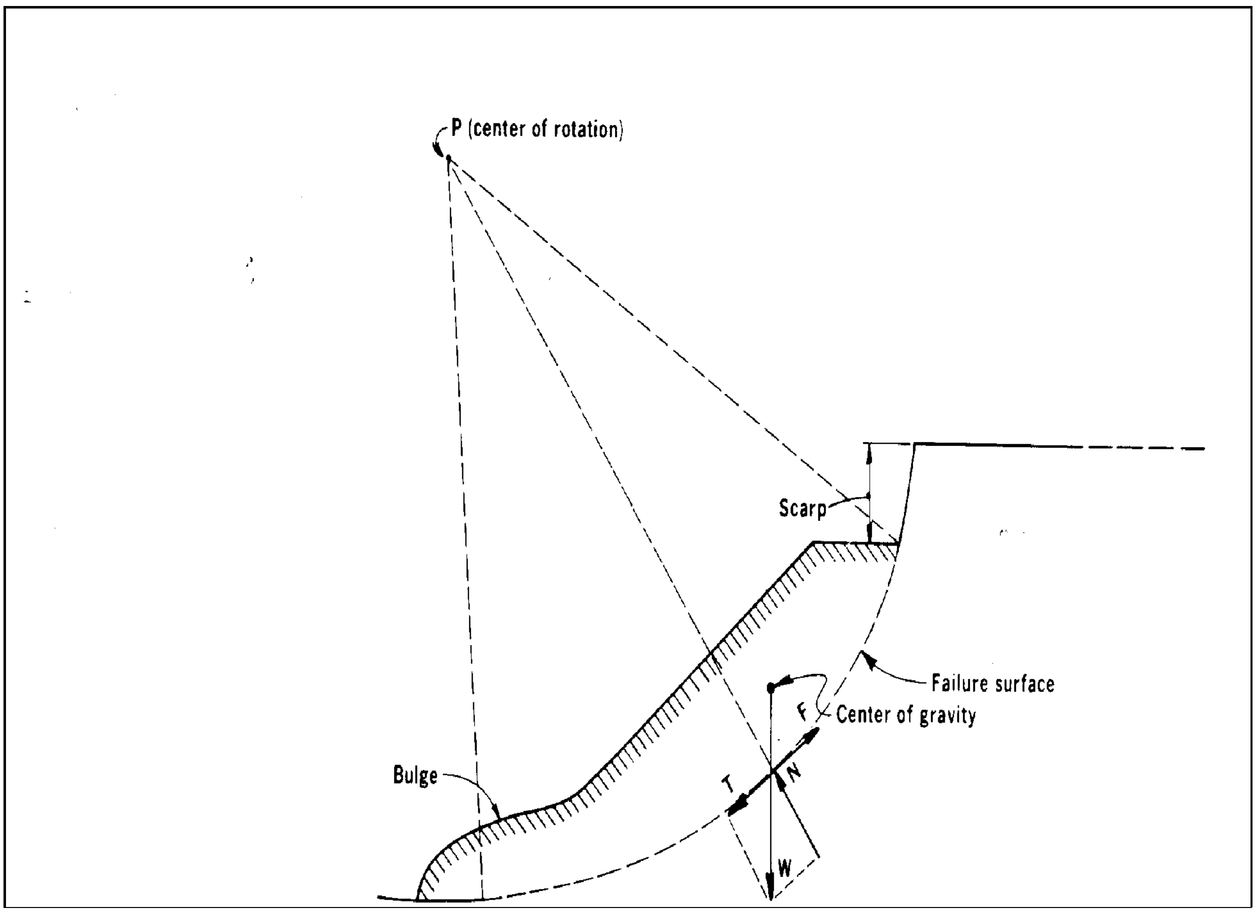


FIGURE 17
Circular arc failure

Factor of Safety (F.S.) =) Acting Forces

When the Factor of Safety is 1.0 or greater, the resisting forces of a particular embankment are equal to or greater than the forces tending to produce movement. The higher the Factor of Safety, the less tendency there is for movement to occur.

The forces at work in a typical wedge type failure are schematically shown in Figure 18. As can be noted, there are normally three slope elements involved in this type of embankment movement:

- an active wedge of material located at the upper end of the failure that acts to cause movement,

- a large central wedge of material within the failure, and

- a smaller passive wedge of material located near the toe of the slope that acts to restrict movement.

The balance or imbalance of forces acting on each of these wedge elements determines the potential for movement along the various failure surfaces.

In the instance shown in Figure 18, the embankment foundation is inclined and contains a layer of weak material. The weight of the material in the central wedge (T_{cw}), is supported by the force (N_{cw}) of the foundation. However, because of the inclination of the foundation and the slippage plane provided by the weak foundation materials, an unbalanced resultant force (T_{cw}) tending to produce wedge movement, is created. This active force is resisted by the shear strength of the materials along the failure surface exterior to the base of the central wedge. If this shear strength (F_{cw}) is not large enough to counterbalance the opposing active force, wedge movement may occur. Whether or not movement does occur is contin-gent upon the forces at work in the remaining two wedge elements.

The weight (W_{pw}) of the passive wedge element is supported or offset by the materials beneath it. The inclination of the failure surface is toward the central wedge, therefore the resultant force within this portion of the slope is essentially passive (i.e: resi-sting slope movement). If the weight in this element is large enough, it can effectively counteract the movement forces in the remainder of the slope that are tending to produce a wedge failure. In many cases where analyses show a high potential for slope movement, it is prevented by adding more material (and weight) to the toe area of the slope to increase this passive or resisting force.

The remaining critical element is the active wedge. Its configuration is essentially a downward thrusting wedge that is attempting to separate or move the remaining wedge elements away from the rest of the embankment. The size of this active force is dependent upon the weight (W_{aw}) of the material in the active wedge and the size of the resisting force (shear strength) located along the exterior of its sloping base (F_{aw}).

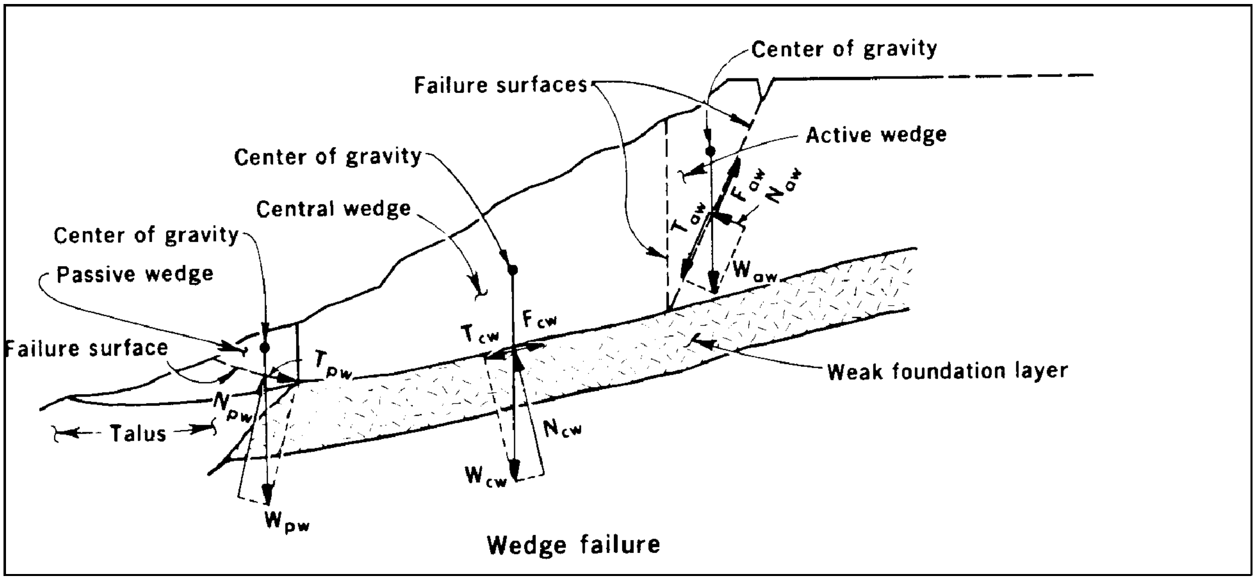


FIGURE 18
Simplified mechanics of slope failures

By discussing each of the three elements of the wedge failure separately, it has been shown that each is either active (tending to move) or passive (resisting movement), depending on the force imbalances that exist within each element. The Factor of Safety for this wedge failure example is thus determined by dividing the sum of the individual resisting forces by the sum of the forces tending to produce movement. When the Factor of Safety is determined to be too low for the site, then some of the following measures may be taken to prevent a potentially hazardous condition.

Adding material at the toe of slope - It can be surmised from the above discussion, and from Figures 15 and 16, that additional material placed at the toe of either the circular or wedge failure planes will increase stability. In effect, this type of modification increases the resisting forces present in the embankment, thus increasing the Factor of Safety. Adding material at the toe of a slope (in accordance with a proper design) is the most common procedure for improving stability.

Removing material from the top of the slope - Removing a portion of the material at the top of the circular segment in Figure 15 would reduce the weight of this segment at a point furthest away from the center of rotation (P). The resulting effect would decrease the active forces and increase the Factor of Safety. The benefit from this type of action is more obvious if applied in a wedge failure situation.

Removing material would reduce the force of the active wedge, which is the major force tending to cause movement. Although often used to improve stability, removing material from the top of a slope is less frequently used than adding material at the toe.

Increasing the strength of embankment materials - For new embankments, slope stability can be improved by maximizing the strength of critical portions of the embankments through the selection of materials, or through the specification of special placement and compaction procedures. At existing embankments, however, it is seldom possible to increase the strength of material deep within the embankment.

3. Effects of Water on Slope Stability -

The above slope failure discussion purposely did not include the very critical effects water has on the mechanics of stability. This section addresses some of the more basic, water related factors that are considered when analyzing slope stability.

Some water is normally present in almost all soil and refuse materials. When this water is simply retained within the voids between soil particles, it does not have a major effect on the mechanics of stability. However, when the water is free to move or flowing through the embankment material (as when seepage occurs from an impoundment), it may have a major impact on stability. Portions of a refuse structure can become saturated due to through-embankment seepage from impounded water, groundwater infiltration and/or unusual rainfall conditions. In these saturated areas the water moves between and around individual particles and a level of equilibrium is established. As shown in Figure 19, this free water surface is termed the phreatic surface. Due largely to gravity, the typical phreatic surface decreases in elevation from the impoundment point of entry as it progresses through the embankment.

All material particles below the phreatic surface are acted upon by the natural buoyant force that water exerts on all submerged bodies. Thus, the friction or interlock strength between individual particles is reduced, without significantly changing the overall weight of the circular segment. Therefore, the force (W) acting to cause movement is essentially unchanged, while the force (F) tending to resist movement is greatly reduced. When using the Factor of Safety formula discussed in the previous section, it can be seen that the reduction in the resisting force will correspondingly reduce the factor of safety. A corresponding discussion about wedge type slope failures would also show that the buoyant effect of seeping water will similarly reduce the safety factor.

4. The Effect of Slope Angle (Steepness) and Height of Slope Stability -

The mechanics of embankment slope failures are directly influenced by the angle of slope or steepness of the slope face, and can also be influenced by the height of the slope. The interrelated effects of slope angle and height are shown in Figure 20, using a typical circular arc failure example.

The effects of the slope steepness can be seen by comparing Figures 20a and 20c. In both of these sketches, the slope has the same height (H_1). Considering the two failure arcs (both containing approximately the same weight), two factors become apparent.
For the steeper slope, the length of the failure surface (L_1) is shorter, while the steeper angle of the failure surface reduces the normal component of W, and therefore reduces the frictional resisting forces.

The first of these factors tends to decrease the resisting force, while the second factor tends to increase the movement force. Using the factor of safety equation, it can be seen that both of these effects combine to reduce the factor of safety.

By comparing Figures 20a and 20b, the effect of slope height in the case of steep

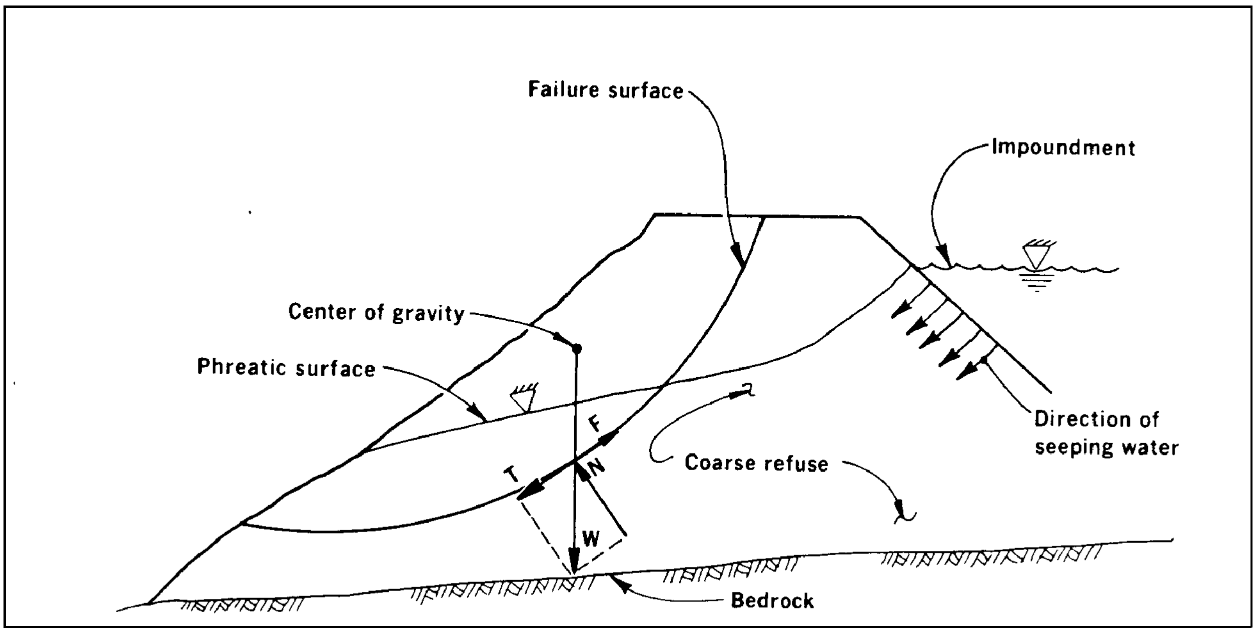


FIGURE 19
Increased slope failure potential due to seeping water

slopes can be seen. The additional weight (W_2) of the higher slope, is located further from the center of rotation and therefore adds a larger component of active force. At the same time, the additional length of failure surface is comparatively small, and very steep, adding relatively little to the resisting forces. These combined effects can result in a significant decrease in the factor of safety of the slope.

Comparison of Figures 20c and 20d reveals that in the case of a shallow slope, adding more height may not have nearly as much impact, because the additional weight (W) also has a much longer associated failure surface.

Despite the above considerations, it is sometimes necessary to construct a refuse embankment with slopes steeper and/or higher than would otherwise be used. The slope stability disadvantages can be moderated somewhat by carefully compacting the embankment materials in critical areas. Even though the resulting slope is slightly heavier (denser), the corresponding increase in the strength of the slope materials to resist movement can be much greater. Any time special compaction efforts are required on selected areas near an embankment slope, the designer must consider the additional related effects of this compaction, such as a corresponding reduction in permeability and its effect on seepage flow.

Once a design has been accepted and an embankment constructed, it is not only unwise but dangerous to indiscriminately excavate access or haul roads into the face. The steepened slope could fail suddenly although not immediately. Any such plan should be evaluated prior to implementation.

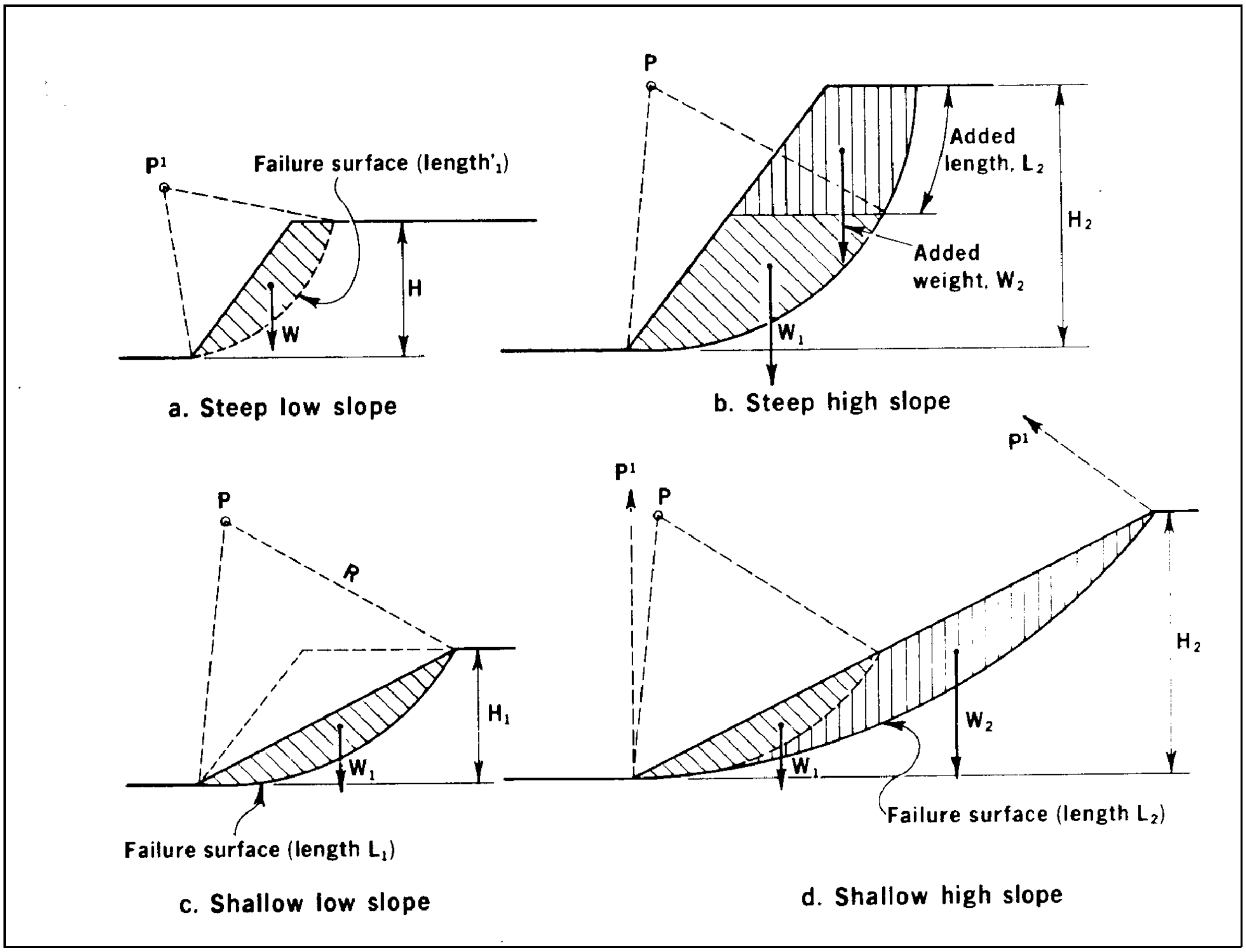


FIGURE 20
Effect of slope steepness and height on stability

5. <u>Secondary Effects of Seepage on Stability</u> -

The above discussion briefly describes the major effects of seeping water that must be considered when evaluating embankment stability. However, when properly planned, an embankment can be designed to safely pass large quantities of seepage under controlled conditions. This is an important consideration, because **it is virtually impossible to totally eliminate seepage from impounding refuse embankments.** Therefore, a designer must plan and properly provide seepage control within the interior of the embankment and its foundation area. Failure to provide this control, can result in the following two types of adverse structural conditions.

Piping - Uncontrolled seeping water passing through an embankment can pick up and transport fine particles of refuse material. As this process continues over time, larger and larger particles can be removed from the interior of the embankment or foundation and deposited on the downstream slope face, valley wall, or downstream area at the seepage discharge point. The resulting discharge opening can gradually enlarge as this piping extends into the embankment, foundation, or abutment toward the point of entry of the seepage. Eventually, lineal voids or pipes are extended entirely through the embankment, foundation, or insitu materials and water flows freely from the impoundment. If uncorrected, this piping can eventually cause the embankment to fail through breaching.

Structural Corrosion - Most refuse materials, if oxidized in the presence of water, will produce acids that are quite corrosive to metallic drainage structures and lime base materials, such as limestone and concrete culverts. Uncontrolled seepage through loosely compacted refuse can therefore produce long-range, adverse structural conditions and even failure of an embankment.

The design procedures most commonly used to discourage through-embankment piping on new refuse structures, directs the seepage through drainage filters consisting of consecutive layers of gradually increasing material size. Examples of this technique are shown in Figure 21. As can be noted, seepage can be controlled either by constructing a drainage filter in the toe portion of the embankment or by installing drains surrounded by appropriate filter materials. As shown, the grain size of the filter materials generally increases in the direction of seepage flow.

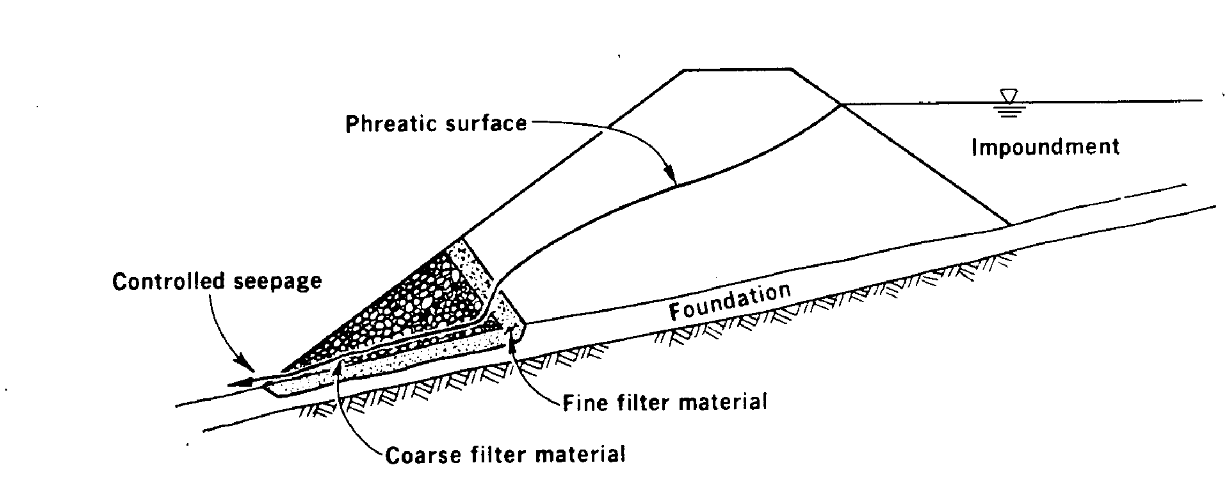


FIGURE 21
Toe filter drain

In the instance of an existing refuse facility with seepage problems, appropriate drainage filters can be applied externally to the toe of the embankment, as shown in Figure 22. In some instances, it may also be desirable to excavate portions of the toe to install drain tiles and drainage filters similar to those placed in new refuse structures.

The prevention of acid seepage and its resulting corrosive impact on a refuse structure is more difficult to achieve. Assuming through-embankment seepage will be present in most refuse facilities, the only means available to a designer to control acid seepage is to prevent the formation of acid. This is routinely attempted through compaction, thus denying oxygen access to the coal refuse. Despite this construction activity, it is virtually impossible to eliminate all refuse oxidation in some facilities. A designer must therefore anticipate corrosion and minimize its impact through the use of adequate corrosion protection or non-corrosive materials in critical embankment areas. Thus, the use of plastic pipe or asphaltic coated pipe in critical drainage structures may be specified. Similarly, acid-resistant rock such as non-calcareous sandstone should also be used in place of limestone. Long-term corrosion of concrete structures must be carefully monitored to prevent their eventual failure and resultant damage to the refuse embankment.

D. Hydraulic Considerations

In addition to embankment stability, a major design concern governing the safety of the facility is its ability to safely discharge storm runoff during periods of unusually high rainfall and under normal conditions. This is a particularly critical concern when dealing with impounding refuse facilities that could release large volumes of floodwater in the event of a failure. When planning and designing impounding structures, a designer must therefore be concerned with the anticipated amount of normal and extreme runoff that will be collected by the impoundment, the normal and extreme volumes of storage that must be safely provided, and the types and number of hydraulic structures that must be provided to safely accommodate not only normal operating conditions, but runoff conditions as well. These design elements are a part of the hydraulic consideration which are briefly detailed in the following discussions.

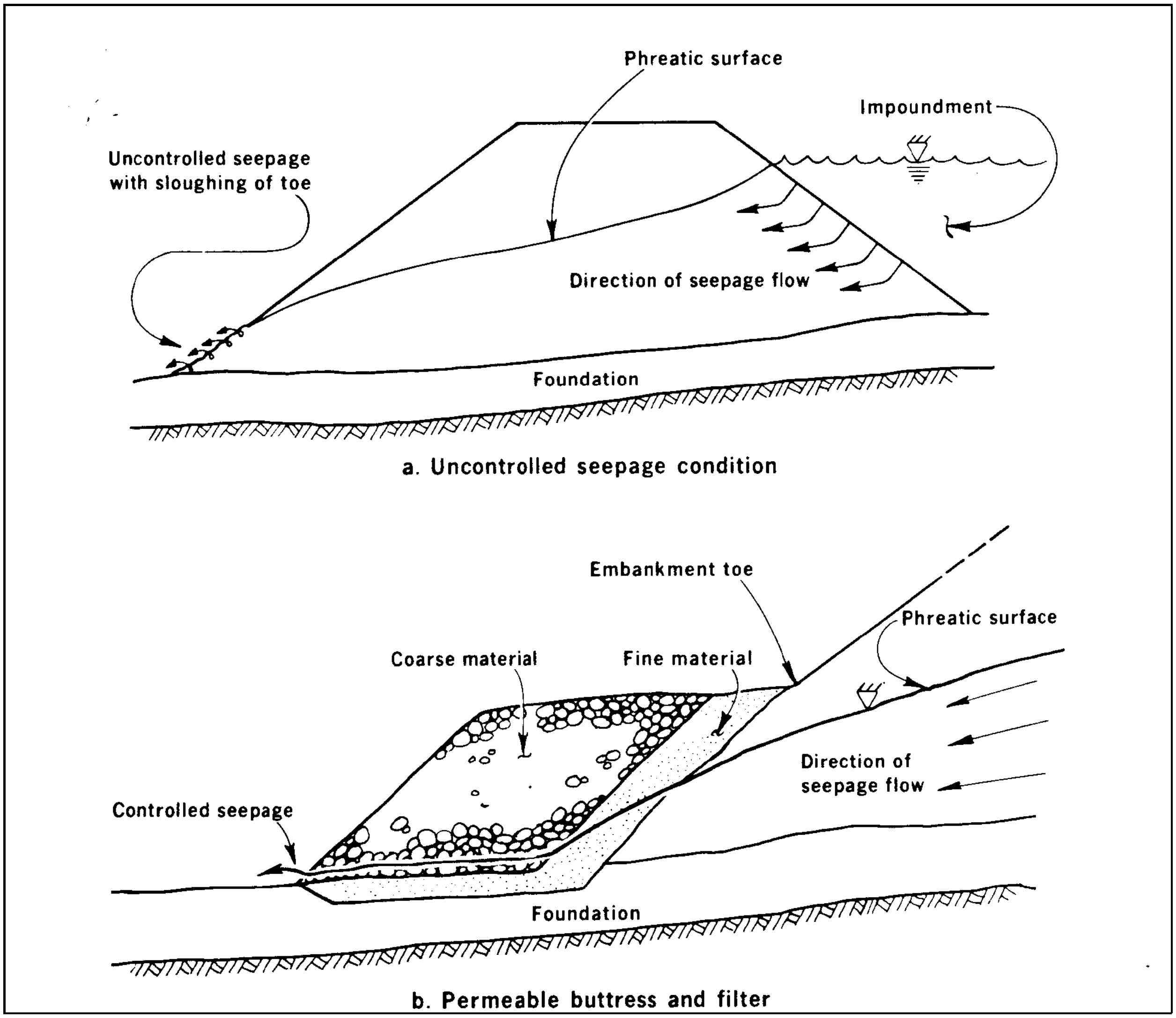


FIGURE 22
Seepage control for an existing impoundment

1. <u>Basic Flow Determinants</u> -

All water flowing into a refuse impoundment constitutes the INFLOW into the facility. While some of this may be stored for either a short or long period of time behind the embankment, the remainder passes through or over the refuse structure and is discharged downstream. Expressed as a formula, this relationship is:

INFLOW = STORAGE + OUTFLOW

In the instance where a refuse facility has no storage capacity, **INFLOW** then equals **OUTFLOW** and the hydraulic structures of the facility must be capable of handling or passing the anticipated **INFLOW.** It should be noted that **INFLOW** includes not only rainfall or storm runoff, but also that volume of water that is produced during the routine disposal of fine refuse.

There are a number of critical determinants of the storm runoff components of **INFLOW**. These include:

- the size of the watershed intercepted by the refuse impoundment;

- the shape and slope characteristics of the watershed that determine how fast the runoff reaches the impoundment;

- the magnitude of the rainfall as measured in inches over a set time span; and

- the magnitude of the rainfall runoff measured in inches over a set time span, where runoff equals the rainfall minus losses due to infiltration into the soil and that due to retention by vegetation.

The amount of runoff produced by a given rainfall will always be less than the amount of rainfall itself. As indicated above, after rainfall hits the watershed and begins to flow downhill, a percentage of this water infiltrates the soil and becomes temporarily trapped in its pores. Another portion is intercepted by the leaves of vegetation in the watershed and never becomes a part of the runoff. The net runoff, therefore, is a function of the soil characteristics, the vegetation, and the average slope of the watershed.

One of the most critical factors involved in planning the hydraulic structures of a refuse facility is the amount of rainfall used in their design. This design criterion varies widely between geographic locations and with the particular frequency of the rainfall or design storm chosen. Allowing for rainfall variation between geographic locations (i.e: southern West Virginia versus southern Illinois) is a relatively straightforward procedure because of the large amount of available rainfall data. However, choosing the particular design storm (i.e: the extreme runoff condition) that a specific hydraulic structure must safely accommodate, is considerably more involved. Each hydraulic structure is designed on the basis of its function within the overall hydraulic plan for the refuse facility, its relative importance within this overall plan, and the overall safety hazard of the facility to downstream areas in the event of failure. All these factors are interdependent and vary with each design situation.

When plans for emergency outlet structures at an impounding facility are being checked for discharge capacity, diversion ditches are normally neglected as being part of the overall discharge system. If a diversion ditch is being considered to pass runoff in lieu of a spillway, the ditch must be designed and constructed under the same design specifications as a spillway. Under normal conditions, diversion ditches around a refuse pile or an impoundment should be designed in accordance with appropriate State regulations.

Current prudent engineering practices require a conservative approach in order to provide maximum flood protection for water retention structures located where failure may cause loss of life or extensive property damage. In this situation, the design of water, sediment, or slurry impoundments should be based on the probable maximum flood (PMF) that produces runoff in excess of that produced by a generalized 6-hour probable maximum precipitation (PMP) event. There are various hydrometeorological combinations that produce a PMF and it is the responsibility of the designer to select the correct combination based upon current, prudent, engineering practices. If it can be shown that the failure of an impounding structure would not cause loss of life or otherwise endanger people, then a lesser design criteria can be used if such a decision can be substantiated. A 100-year frequency storm of 6-hour duration (one percent probability) is the minimum design storm permitted for any water, sediment, or slurry impoundment.

2. Types of Hydraulic Structures -

This section briefly identifies the major types of hydraulic structures that are commonly used in the design of coal refuse disposal facilities. Also covered are typical examples of each structure and comments about their general function.

Spillways - Spillways are provided on refuse facilities with impoundments and are intended to function as a safety mechanism to discharge that portion of the **INFLOW** that exceeds the maximum discharge capacity of the decant (where applicable) plus the available safe storage in the impoundment. Typical spillways are shown in Figure 23.

The excavated rock spillway, illustrated in the upper portion of this figure, is the most common type of spillway used in constructing refuse facilities. As can be noted, a channel is cut into rock around the abutment of the refuse embankment. In instances where a spillway is excavated around an abutment in either soft or weathered rock, or where no rock is present at all, the bottom and sides of the channel should be lined with a protective covering. Where failure of the spillway could result in failure of the embankment and probable loss of life, riprap channel protection is no longer generally acceptable. The designer shall consider alternate erosion protection measures and/or channel realignment/relocation where appropriate. These items will be shown in the design drawings. Whether cut into rock or not, particular care must

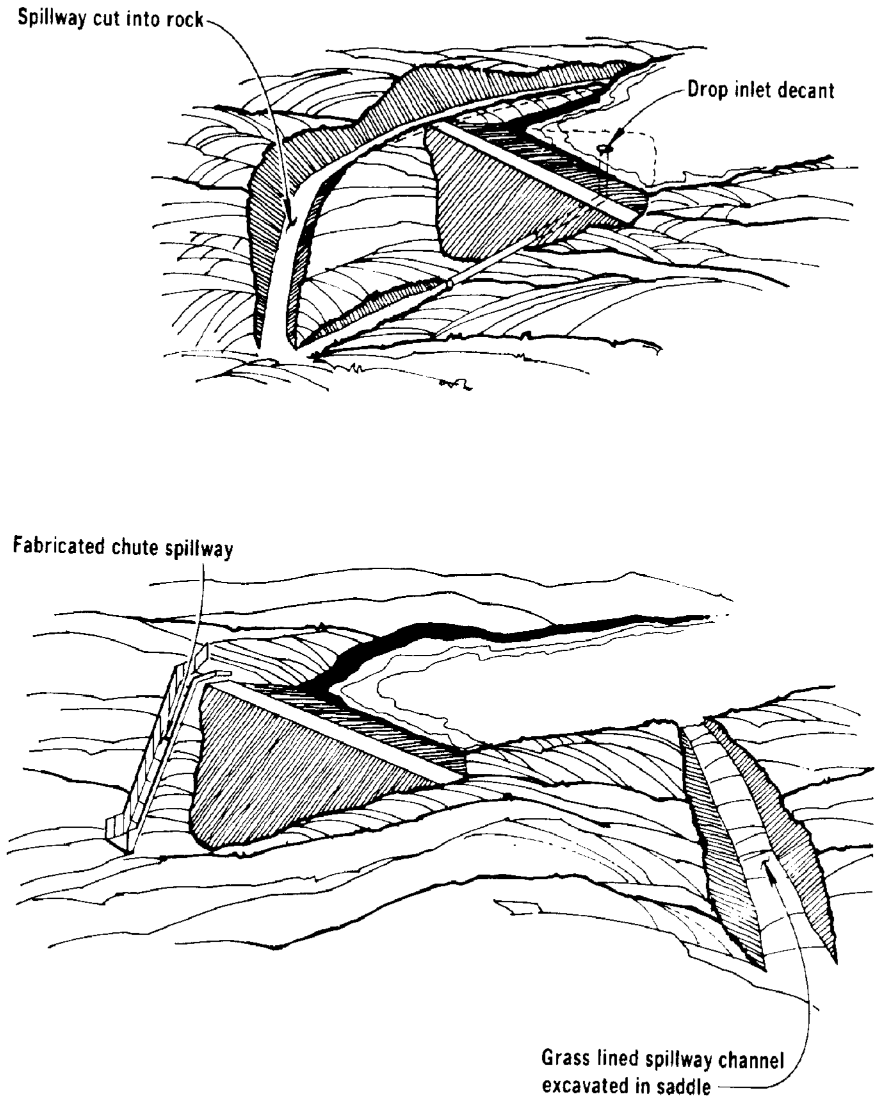


FIGURE 23
Spillways and decant in cross-valley impoundment

be taken to prevent excessive sloughing of side slope material into the spillway channel. Clearing of trees and other materials above the spillway that may fall into the channel during periods of heavy rainfall is also an inspection consideration.

The fabricated concrete chute-type of spillway shown in the lower portion of Figure 23 is infrequently used with coal refuse impoundments because of the frequent changes in the height of the refuse embankment. Their relatively high construction cost can not be justified for anything other than a long-term use as in the case of earth or rockfill dams. Fabric formed concrete (cement grout) open channel emergency spillways have been successfully used in some areas of the country at low hazard impounding facilities. Where rock is not available and the soils are erodible under the velocities anticipated, the product may be economically acceptable.

The grass lined spillway, shown in Figure 23, is a desirable type of discharge structure if permitted by topographic conditions. This type of spillway is normally placed in a natural saddle or low point along the perimeter of the impoundment. Spillway channel excavations lined with synthetic fibrous materials have been successfully utilized where grass alone is inadequate against velocity induced erosive forces. The mats bond the individual root structures into a more homogeneous, interwoven mass capable of resisting somewhat higher velocities. Topographic and hazard limitations often restrict the exclusive use of this type of spillway.

Many combinations of spillways can be constructed in addition to the ones described above. Large pipes, usually with risers, are sometimes installed beneath or through an embankment to function as a spillway. In this type of installation, the downstream discharge must be carefully controlled by providing protective discharge chambers (or some other type of energy dissipators) or a protected channel in order to prevent erosion of the refuse embankment. In instances where successive spillways must be constructed to accommodate changing impoundment elevations, a system such as that shown in Figure 24 may be specified by the designer.

Decants - The basic purposes of a decant system are: (1) to routinely discharge clarified surface water from an impoundment after the fine refuse has settled; and (2) to slowly discharge storm runoff that is periodically collected in an impoundment during large rainstorms. Schematic examples of typical decant systems are shown in Figure 25.

As noted on these sketches, a typical decant can have a number of inlets, each at a different elevation. The elevation of the lowest inlet is set low enough to minimize the depth of clarified water, yet high enough to allow a reasonable period of operation before accumulation of fine refuse requires that the next higher inlet be used. When such a change is required, the next lower inlet is simply closed and the clarified water is allowed to accumulate until it reaches the next higher inlet.

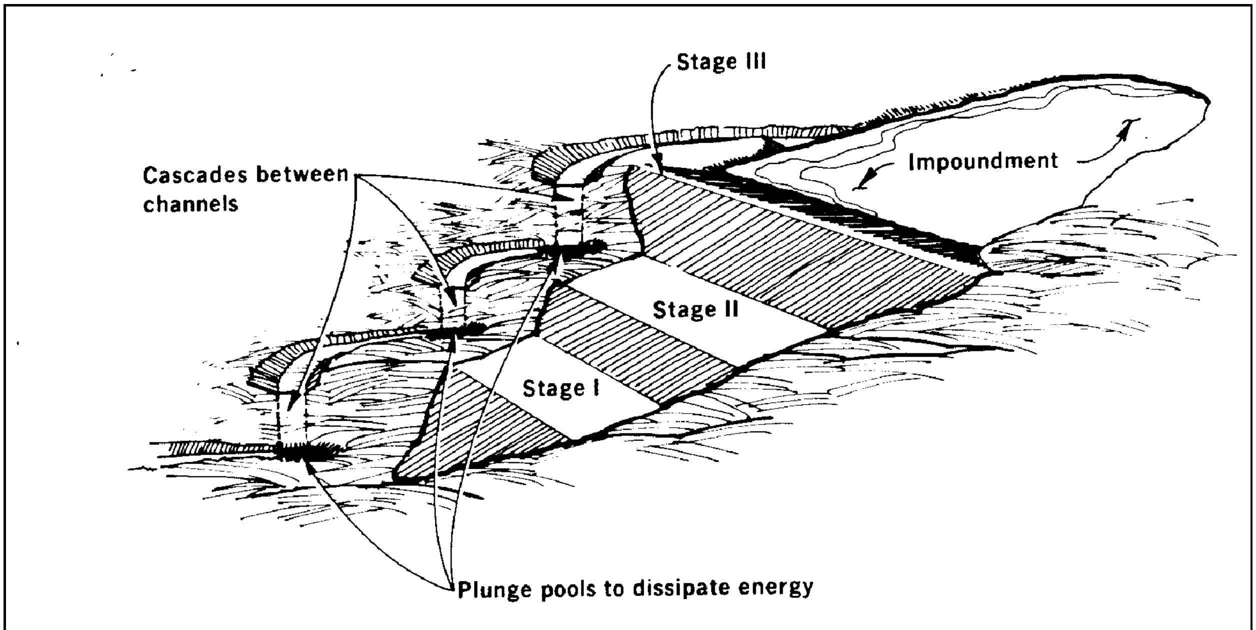


FIGURE 24
Cascading spillways for staged embankment facility

As cited previously, the decant system and spillway designs are interdependent and the sizing of the spillway is contingent upon the ability of the decant to effectively discharge collected storm runoff within a set period of time. If, due to clogging or some other type of malfunction, a decant is unable to operate as intended, then the overall hydraulic plan for the impoundment is impaired and serious conditions may occur. To avoid such disruptions, decant inlets are normally protected

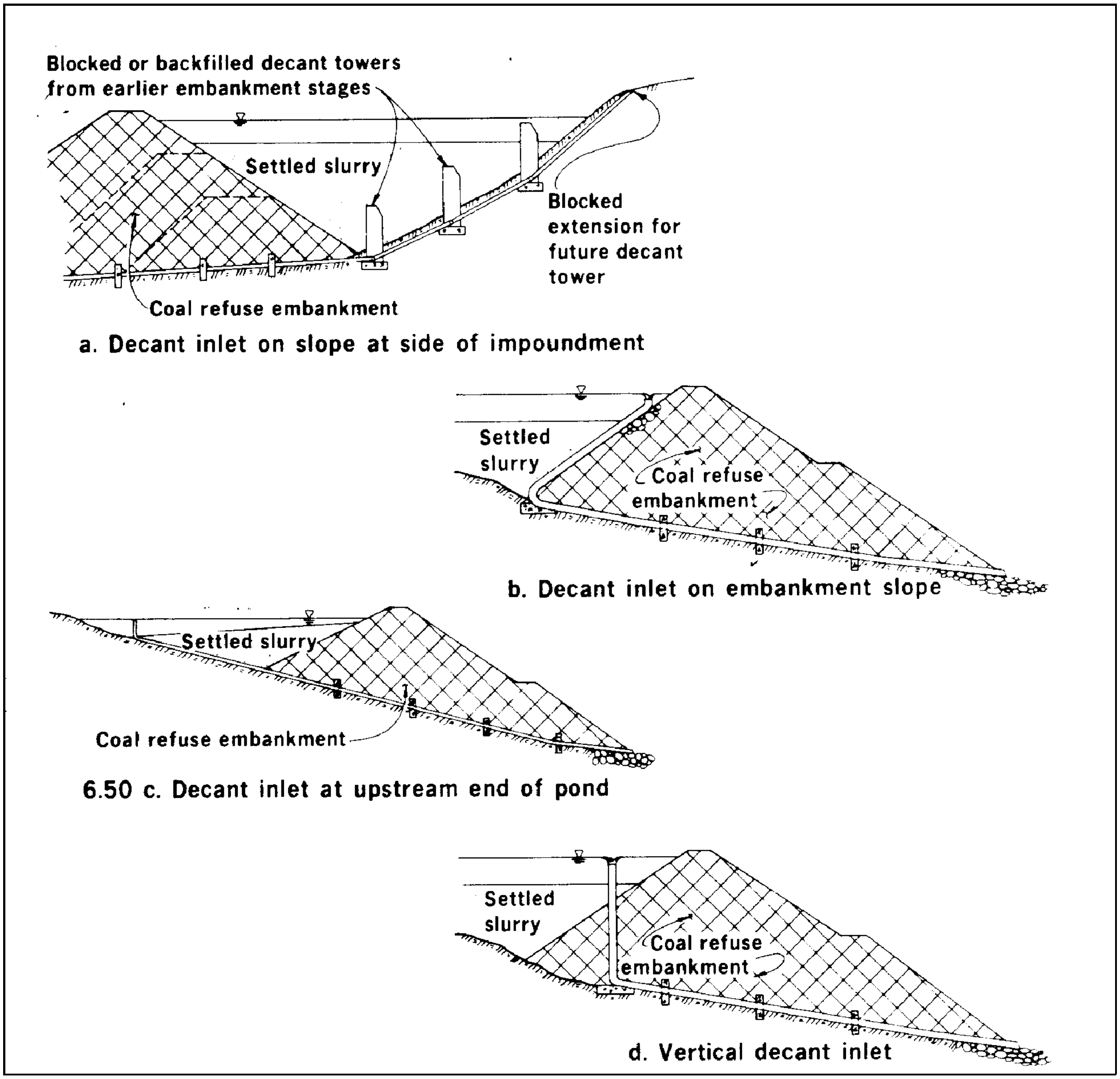


FIGURE 25
Various decant inlets with under-drain pipes and anti-seep collars

with trashracks (cage-like covers) to prevent floating logs and other debris from interfering with normal inflow.

As shown in Figure 25, the flow in a decant is normally directed through the pipe under the refuse embankment to be discharged downstream. The placement of this pipe, and particularly the backfilling and compaction around and above it, are extremely critical steps in the construction of the refuse embankment. Many embankment failures have occurred because of excessive water seepage adjacent to these pipes as a result of poor compaction. To avoid the chance of this occurring, most decant pipes under embankments have concrete or metal anti-seep collars, or cutoff walls that restrict seepage along the pipe. All collar material must be compatible with the conduit. Quite often an asphaltic mastic or similar material is placed between the pipe and collar or within the collar to accommodate thermal expansion and contraction. Construction plans should also specify detailed compaction requirements along decant pipes to avoid the creation of voids that would be susceptible to seepage.

Since the late 1970's, several well known dam design and construction agencies have stopped using anti-seepage collars are now relying on suitably graded granular filters around the outlet portion of the conduit. MSHA does not restrict the use of either control method, but the user must incorporate all the parameters of any method selected.

Pumps - Pumps normally discharge very low capacity when compared with decant pipes or open channel spillways. Pumps are generally unacceptable in routing storm runoff through impounding facilities. An MSHA Information Bulletin, "Reservoir Evacuation by Pumping" provides more detail on pumps.

Diversion and Collection Ditches - Diversion and drainage collection ditches are usually not critical elements of the overall hydraulic plan for a refuse facility, although their presence and function can be quite important in terms of minimizing downstream environmental damage and reducing erosion and maintenance on the refuse embankment itself.

A number of factors must be considered when designing diversion ditches. Of particular importance is the dynamic nature of the refuse embankment itself. Because the size and configuration of the refuse embankment is constantly being changed, the size and location of runoff collectors must also be periodically changed. Thus, many diversion ditches are only used for a relatively brief period of time, which does not justify expensive construction procedures or materials.
In many instances, it is impractical to construct diversion ditches large enough to accommodate runoff from very large storms without overtopping. Depending on the location and relative importance to the overall safety of the refuse facility, periodic overtopping of diversion ditches is not normally a serious matter. However, where overtopping might cause problems, drainage ditches must be sized large enough to prevent overflowing. Similarly, care must be taken to minimize the chance of clogging, due to either the accumulation of debris or through the collapse or sloughing of the sides of the ditches.

In instances where a diversion ditch is critical to the safety of the refuse facility and/or where it will function as a major permanent drain, it must be designed to accommodate the appropriate design storm, and constructed in a manner that will guarantee its long-term use. The side slopes must be relatively flat to minimize sloughing of material, and should be protected with either vegetation or riprap. Similarly, the bottom of the ditch must also be protected from erosion through the use of similar materials or in some cases, through the use of concrete.

The designer must also consider channel freeboard to accommodate wave action due to roughness and super elevation due to changes in alignment. Since ditches are assumed not to flow full, freeboard values will be shown in the design drawings.

Culverts - There are normally only two types of culverts associated with coal refuse facilities: (1) relatively minor culverts under access roadways and (2) more critical culverts that pass storm runoff past the embankment in a safe manner. Of the two types, the roadway culvert is by far the most common.

The size and design of road culverts are contingent upon their location and whether or not repairing roadway damage due to a washout would be prohibitively costly. If, for instance, a culvert is to be installed under a relatively minor, unsurfaced access road that could be closed for repairs without interfering with the overall operation of the refuse facility, then a smaller and less costly culvert might be cheaper in the long run. However, a culvert under a critical access road must be able to accommodate a much larger storm runoff in order to avoid costly operational shutdowns in the event of a washout. The appropriate design storm in both of these instances would vary in accordance with the relative importance of the culvert.

The second and more important type of culvert is installed in association with cross-valley embankments to control the amount of temporary storage behind the embankment that occurs after a heavy storm. In most instances it is impractical to install a culvert large enough to immediately pass or accommodate all storm inflow; thus, a temporary impoundment is created. The duration and size of this body of water are determined by the capacity of the culvert installed. The function and hydraulic requirements of the culvert are similar to those for a decant structure. Also similar is the need to protect the intake end of the culvert with a trashrack. This is particularly important for smaller culverts (i.e: less than four feet in diameter) that are difficult to clean out once they become clogged.

Pipe spillways that operate under pressure must be watertight to prevent the piping of backfill material along the outside of the conduit and to prevent hydraulic pressure from being transmitted to the backfill material. An assurance is to pressure test all pipes prior to backfilling to ensure integrity. For additional information on pipe installation MSHA's Information Bulletins on "Design of Pipes for External Loading" and "Pressure Testing of Principal Spillway Conduits" may be obtained.

E. Additional Considerations

A last, but overriding design consideration is the ultimate disposition of the refuse facility, once it is abandoned. Prior to initiating construction of new refuse facilities, or the modification of existing structures, an operator must submit plans to MSHA for their final abandonment. These plans specify the final configuration of the disposal facility, identify final drainage patterns and structures, and detail the overall provisions for establishing vegetation on the completed facility. Each step of the construction process throughout the life of the facility is accomplished in conformance with this plan for final abandonment.

There are many acceptable procedures for preparing a refuse disposal facility for abandonment. Selection of the best procedure is dependent upon the unique conditions of each site. There are a number of ways for planning for abandonment of a refuse disposal site. One of the more important items is the need to obtain a continuous cover of topsoil and vegetation over the entire facility. This can be accomplished either in increments as construction progresses, or after construction is complete. Other means of obtaining a satisfactory cover is planting directly on the refuse material, using various refuse conditioners and additives as required, or a combination of both of these techniques. Regardless of the method used, the desired end product and the reason for planting is to establish a protective seal or barrier between the reactive coal refuse and the agents of chemical reaction (water and oxygen).

If left uncovered, oxygen and water are free to infiltrate the refuse material. Two undesirable conditions will then occur, depending on the characteristics of the refuse and its placement. Acid leachates will be produced that can seriously alter downstream water quality. This drainage can also result in the corrosion of exposed metal surfaces or embankment structures. The oxidation of coal refuse can also result in critical thermal buildups and possible spontaneous combustion of the refuse materials.

Another important function of the vegetative covering is to minimize the occurrence of erosion on surfaces of the refuse facility. If allowed to progress over an extended period of time, erosion can cause serious structural problems and may even result in the ultimate failure of the facility.

CHAPTER 4 - INSPECTION PROCESS

INTRODUCTION

The following discussion covers impoundment and dam inspection procedures; however, most of the procedures described can also be applied to the inspection of refuse piles.

The construction requirements for impoundments are specified in engineering plans submitted by the coal company and subsequently approved by MSHA. Once a plan is approved, there is an ongoing need to periodically check the operation and condition of the disposal facility in order to determine whether it is in conformance with the approved plan and to see whether any potentially dangerous conditions have developed. Approved plans are also required for the construction of refuse piles where the lift thickness exceeds two feet, or the slope angle exceeds 27 degrees and for the abandonment of impoundments or hazardous refuse piles. The construction requirements for other refuse piles are specified in the regulations.

INSPECTION PREPARATION

If an inspector has not previously visited a particular site, it is recommended that some time is devoted to become familiar with the general area. This is most readily accomplished in the office using US Geologic Survey maps, recent aerial photographs, previous inspection reports, or a plan view of the facility. The plan view provides the field personnel with the means to accurately record the location of major problems needing further evaluation and monitoring.

During the initial inspections, an inspector should make use of the Periodic Inspection Form and the discussions in this section to be sure that all important items are observed and noted. For quick reference in the field, the main points in this section are summarized in the Summary Outline in Appendix A.

Equipment which may be needed during an inspection includes a tape or rule, an instrument for measuring slope angles, and a camera. The tape or rule may be needed to check critical dimensions, such as the width of a spillway. An Abney level or other device may be needed to check for oversteepened slopes, and a camera is invaluable in documenting site conditions.

It is important that a mine representative accompany the inspector during the inspection. The inspector can obtain information from the representative regarding the operation of the refuse facility.

GENERAL SITE CONDITIONS

During an inspection there are three elements of concern in the general area adjacent to a refuse facility. These are areas of downstream development, the upstream watershed characteristics, and the physical characteristics of any stream flowing away from a refuse facility. All three elements must be evaluated and any critical observations should be noted on the Periodic Inspection Form. One form per site should be completed by an inspector and subsequently submitted to the District's impoundment specialist if apparent deficiencies at a refuse facility are observed.

A. Downstream and Downslope Conditions

The approval of a planned refuse facility is contingent upon the structure being designed in a manner that adequately considers existing areas of potentially threatened downstream or downslope development (Figure 26). As described in Chapter 2, a facility is assigned a hazard potential rating on the basis of an evaluation of existing downstream development. If, as an example, a facility has little or no existing development (i.e: mine facilities, homes, etc.) located in the downstream floodplain, it may be assigned a "low hazard potential" classification and be designed to accommodate only a relatively small storm. However, if enough new downstream development occurs after the facility is constructed, then a change in the design and spillway size may be required to provide more downstream protection. It is therefore important that the inspector notes this construction in the downstream area, and brings it to the attention of the District staff.

In addition to noting all new downstream or downslope developments, an inspector should also note the abandonment or elimination of existing facilities. This may be important in the instance of abandoned mine openings or air shafts that can very quickly become overgrown with vegetation. While not immediately important, knowledge of abandoned installations may be critical to a future modification of a nearby refuse facility.

Another type of situation to be noted involves a non-impounding refuse facility located upstream from an active mine. Figure 27 illustrates the following effects if such a site were to fail.

- An entry could be clogged by the sliding material, possibly trapping miners or shutting off a source of ventilation;

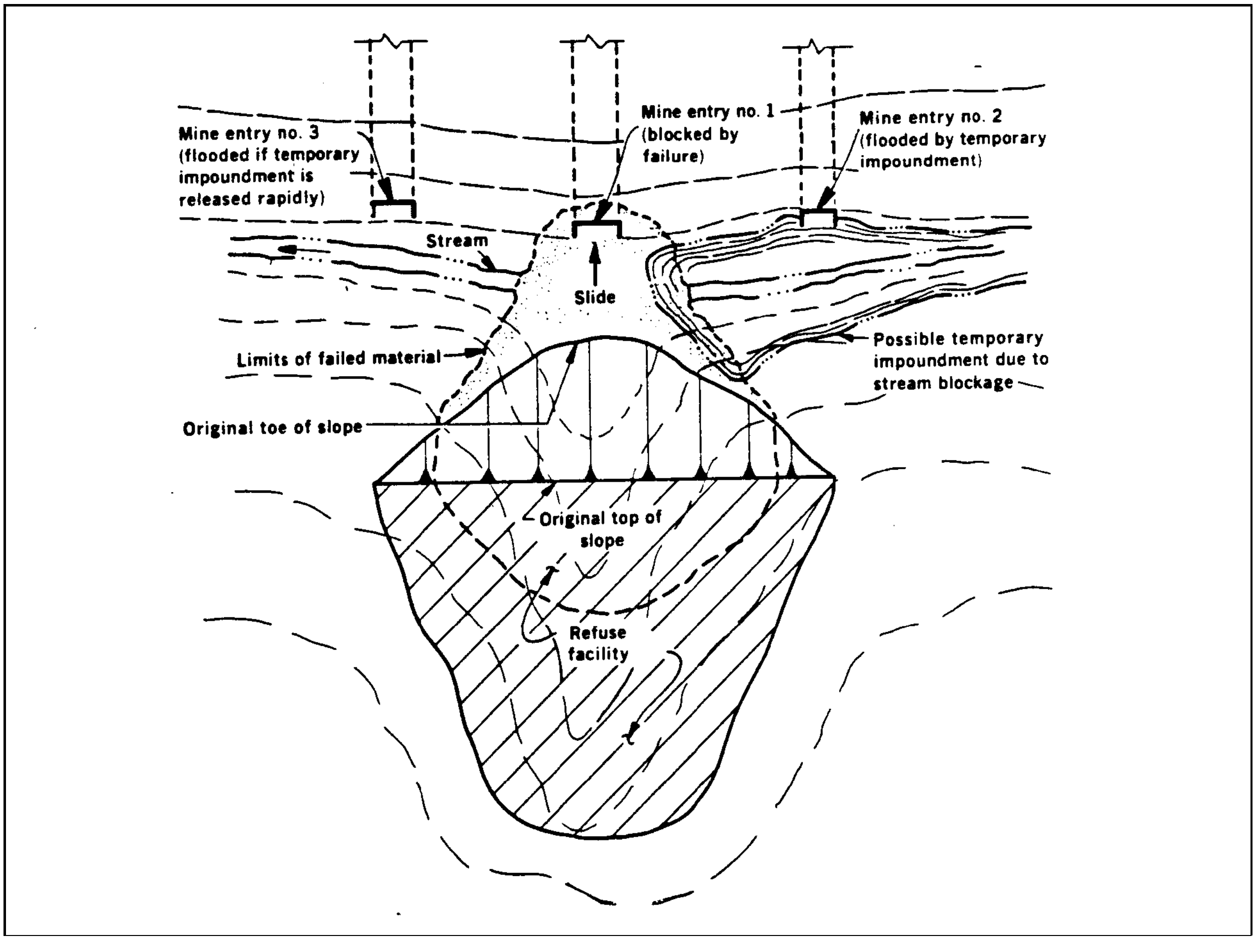


FIGURE 27
Threatened development downstream from a non-impounding, side-hill refuse facility

- temporary blockage of the stream by the material could create a temporary impoundment that might also flood other entries; and

- if the stream blockage is overtopped by the impounded water, it could wash away and possibly cause flooding in the mine.

B. Watershed Conditions

The design of a refuse facility is based in large part upon anticipated watershed runoff flows. Any changes in the watershed that could bring about an increase in the amount of this runoff could have a serious impact on downstream refuse structures. Changes could result from the construction of upstream impoundments, such as recreation ponds or water supply dams. A failure of these structures could have disasterous effects on any downstream refuse facility. During the initial inspection, the watershed conditions should be verified by the inspector and any changes noted. As shown in Figure 28, typical changes in the watershed which should be noted might include the following:

- newly constructed dams;

- changes such as extensive logging, farming or strip mining which would increase runoff;

- changes in the upstream road patterns that may effect the path or volume of water runoff; and

- changes in residential or commercial development.

C. Stream Characteristics

Although not directly related to stability, the characteristics of any stream flowing away from a refuse facility can provide an indication of potential problems. Evidence of refuse siltation in downstream channels may indicate a sedimentation problem that could lead to increased flood damage downstream. Downstream deposition of coal refuse can result from the surface erosion of refuse embankments or erosion of the embankment toe by an adjacent stream. Stream erosion can be corrected by protecting the embankment with riprap or possibly by adjusting the stream alignment.

Stream discoloration, due to suspended solids or acid drainage, indicates possible structural problems that may require remedial action. These types of changes in stream character should be reported by the inspector.

CONSTRUCTION AND SITE CONDITIONS

Many of the unsafe conditions that can occur at a coal refuse facility are due to improper construction techniques and procedures. Others can occur as a result of undesirable operating methods or a lack of site maintenance. Typical examples of these causes include:

- the failure to properly prepare a foundation area;

- improper placement of embankment materials;

- poor location or improper construction of haulage and access roads; and

- an unanticipated increase in refuse volume without adequate equipment to place it.

It is not an inspector's job to constantly monitor facility construction or operating procedures. However an inspector must be able to recognize potentially hazardous conditions and deviations from the approved plan and react accordingly.

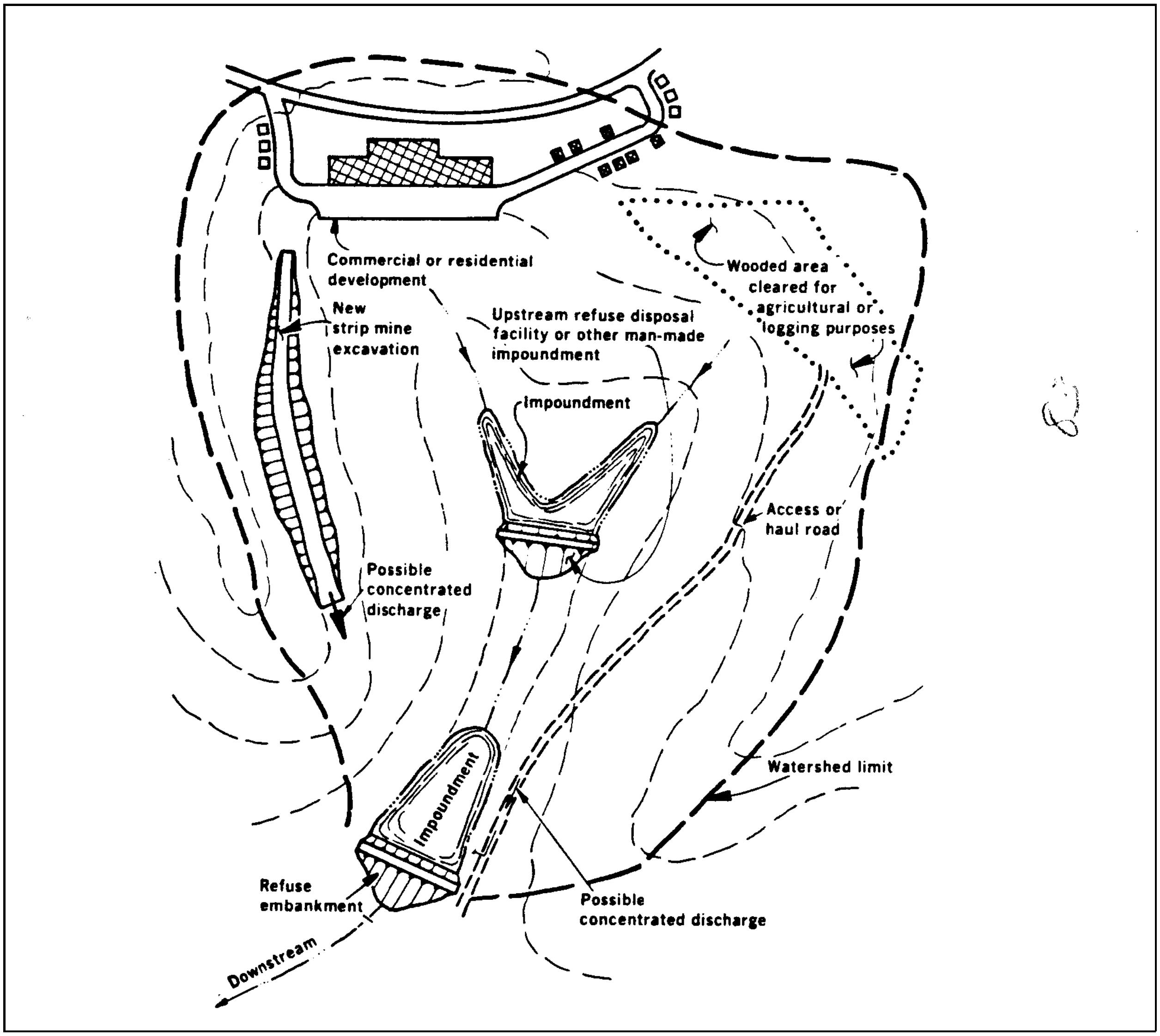


FIGURE 28
Typical watershed activity routinely reported by inspector

A. Foundation Preparation

The foundation area of a refuse embankment or dam should be cleared of all vegetation. Buried vegetation provides a weak and undesireable foundation zone. The existence of partially covered vegetation around the fringes of an embankment indicates that insufficient effort was devoted to preparing its foundation. The approved plan may also call for other foundation preparation measures to ensure stability. These may include soft soil removal, cutoff trench excavation and backfilling, or the placement of special filters in key locations.

B. Placement of Material

Material placement procedures involve a variety of factors that could lead to unsafe conditions. The strength of an embankment depends on the material being properly compacted and this is one of the most important aspects of embankment construction. Plans normally require that the mining company make field density measurements at regular intervals to check that adequate densities are being obtained. Any time it appears that effective compaction is not being achieved, as evidenced for example by soft areas or rutting, this condition should be brought to the attention of the District staff. Such practices are:

- the use of excessively thick lifts which do not permit adequate compaction throughout the lift;

- the failure to scarify and/or moisten lift surfaces when they are too smooth or too dry to properly bond to the next lift;

- the placement of material that is too wet to be effectively compacted; and

- the failure to provide complete coverage of the compaction equipment on each lift.

Due to the importance of these items to the overall stability of the refuse facility, the inspector is expected to note them and any deviations from the approved construction procedures.

Particular attention must be given to the placement of combined refuse. This material is fine coal waste which, instead of being disposed of by being pumped in slurry form, is mixed with the coarse refuse. Due to its high water content, combined refuse can present handling and structural stability problems. Normally it must be spread out and some drying or draining must occur before it can be effectively compacted. Disposal plans involving combined refuse may have special placement procedures, which may differ in structural versus non-structural portions of the embankment.

An inspector or specialist should be on site during the installation of a decant pipe or a drain, and attention should be directed to poor construction practices which could lead to problems later on. For example, the backfill around the pipes must be well compacted so that excessive seepage does not occur along the pipe, and if flexible pipe is used, it is adequately supported. Most of the load carrying capacity of a flexible pipe comes from the support provided by well compacted backfill. Inadequate backfill compaction can lead to excessive deflection and collapse of a flexible pipe. Normally the backfill is placed in thin lifts (typically 6 inches), so that it can be adequately compacted with hand held tamping equipment. Lifts should be placed alternately on each side of the pipe. Approved plans may or may not call for the installation of anti-seepage collars, depending on the particular design circumstances.

When a drain is being installed, the aggregate or larger rock portion of the drain normally must be separated from the embankment material by a filter layer. This filter may consist of a layer of sand or gravel, or in many cases, may be a filter cloth or geotextile. The filter is placed to allow the water to seep into the drain while holding back the embankment material.

With a geotextile, the inspector should be alert to any practices that could result in an opening in the fabric. For example, the base should be fairly uniform so that the fabric does not have to bridge over any large voids. Rocks should not be placed on the fabric, nor equipment operated on it in such a manner which could result in tears. Seams should be either sewn or sufficiently overlapped so that they can not open up.

C. Haulage or Access Roads

Improper construction and maintenance of haulage or access roads can create potentially hazardous conditions. These potential hazards may threaten the stability of the site and the safety of the equipment operators using these roads. An inspector should be aware of the following three types of hazardous road construction practices:

1. <u>Construction of Roads on Existing Slopes</u> -

The construction of roadways on new (embankment) slopes is usually accomplished at the same time the embankment is being constructed. The roadway is extended as the height of the embankment is increased. If done in this manner, few if any hazardous conditions are created. If however, a roadway is cut into a completed slope, serious sliding and erosional problems can occur and affect the stability of the slope, as illustrated in Figure 29.

2. <u>Improper Grading or Drainage</u> -

Whether constructed on new or existing slopes, improperly graded and drained roads will eventually cause stability problems, as illustrated in Figure 30. Runoff concentrated by the roads or in their drainage ditches can cause serious

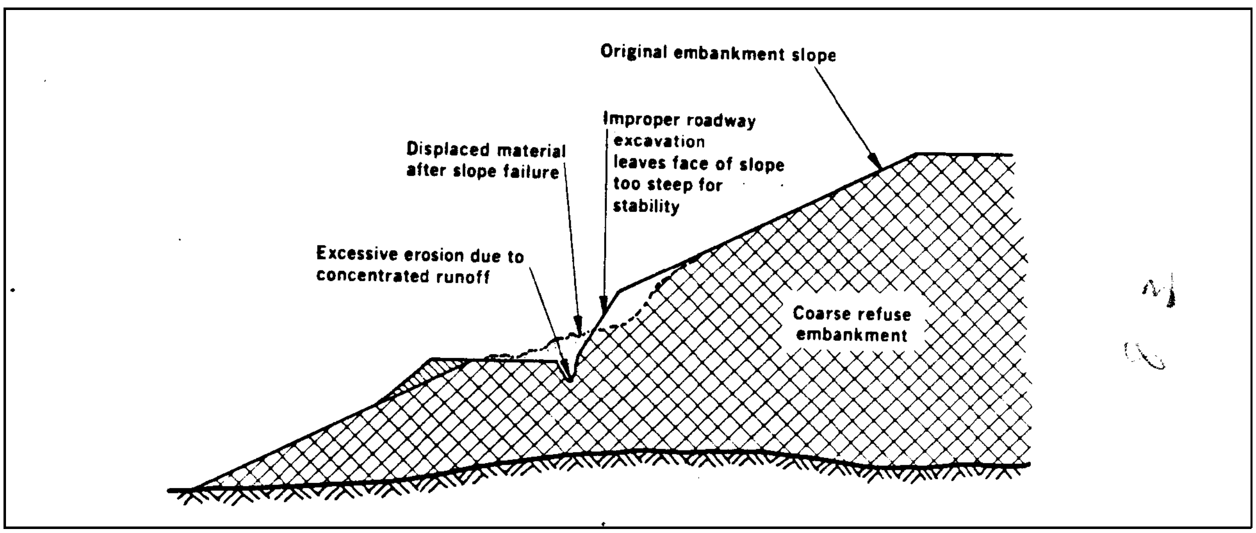


FIGURE 29
Sloughing of embankment material due to improper construction of haul road on existing slope

gully erosion, unless the ditches are properly designed and protected.

3. Disruption of Hydraulic Structures -

In some instances, road construction can result in the impairment or destruction of a facility's critical hydraulic features. An extreme example of this is illustrated in Figure 31. A culvert and roadfill was placed in the spillway, reducing its capacity. This could cause overtopping of the dam during a period of heavy rainfall resulting in possible failure.

EMBANKMENT SLOPES

Inspecting embankment slopes for signs of instability is one of the most important requirements of the inspection process. The four major slope conditions an inspector must look for are areas of unusual steepness, seepage, slope movement, and gully erosion. While a number of indicators of slope instability can be seen from some distance, many can not, and therefore require

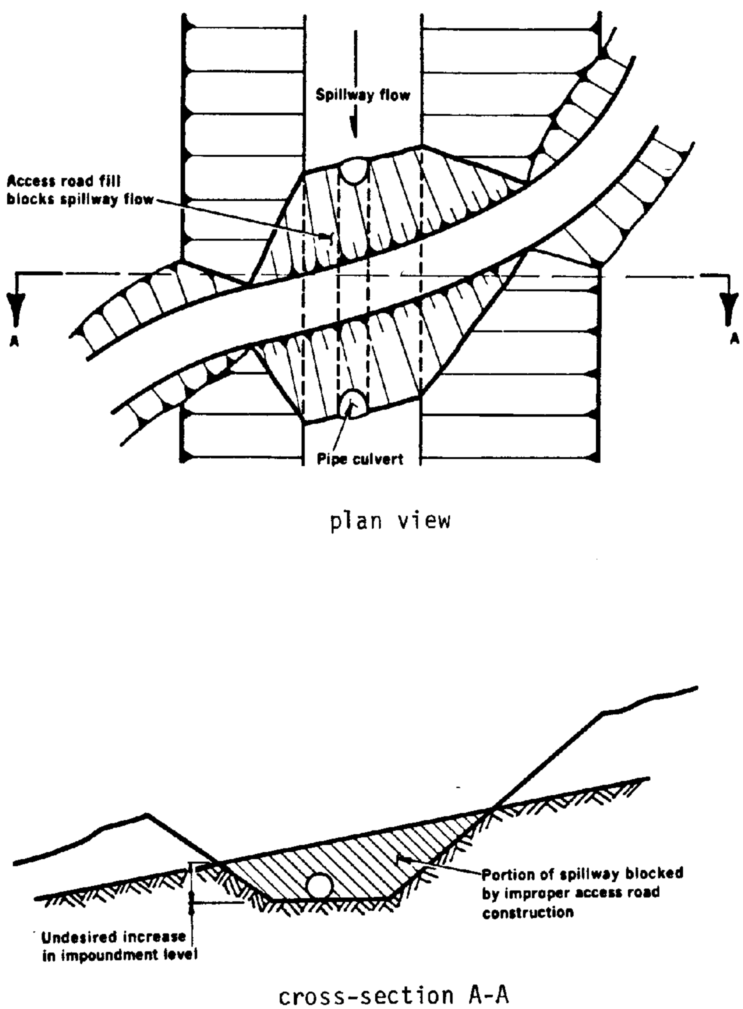


FIGURE 31
Plan view
Cross-section A-A

Improper access road construction resulting
FIGURE 30
Plan view of embankment showing spillway capacity ... structure
erosion due to lack of drainage ditch protection
increase in impoundment height

a relatively thorough slope investigation and a planned inspection route.

A. <u>The Inspection Route</u>

The inspection route is shown in Figure 32. This procedure minimizes unnecessary hiking and optimizes the slope inspection process. While the particular route taken by an inspector will vary, depending on access and the configuration of the particular embankment, the following procedures should be adhered to.

- walk along the entire top (crest) of the structure, making a criss-cross pattern, starting at the edge of the slope for the entire width of the crest, or for a distance equal to one-half the height of the embankment;

- walk down the face of the slope in a criss-cross pattern in order to observe the entire slope face;

- while walking the slope, observe conditions where the slope meets the natural hillside and also inspect this slope for up to l00 feet from the embankment at a number of locations;

- walk along the entire toe of the slope; and

- walk a criss-cross path downstream from the toe to an approximate distance of 100 feet and observe and record any unusual conditions.

B. Steepness of Slopes

To ensure the stability of dam or embankment slopes, they must be no steeper than what is called for in the design. The correct angle or steepness is specified in the approved plan. An inspector should check whether the slope angle is correct or not. Noticeable changes in steepness can be observed by standing on the slope and looking along its length. If a noticeable steepening is observed, the inspector should describe its location in the notes.

C. Seepage Flows

Many embankment failures have occurred due to the unanticipated and uncontrolled seepage of water through the structure and its foundation. Such seepage can weaken a slope by saturating the slope material or by carrying away soil particles in the process called piping. In some cases seepage may not appear on a slope until a facility has been in operation for several years. Therefore, the location of all seepage areas is very important. It is a good idea to inspect impounding structures shortly after

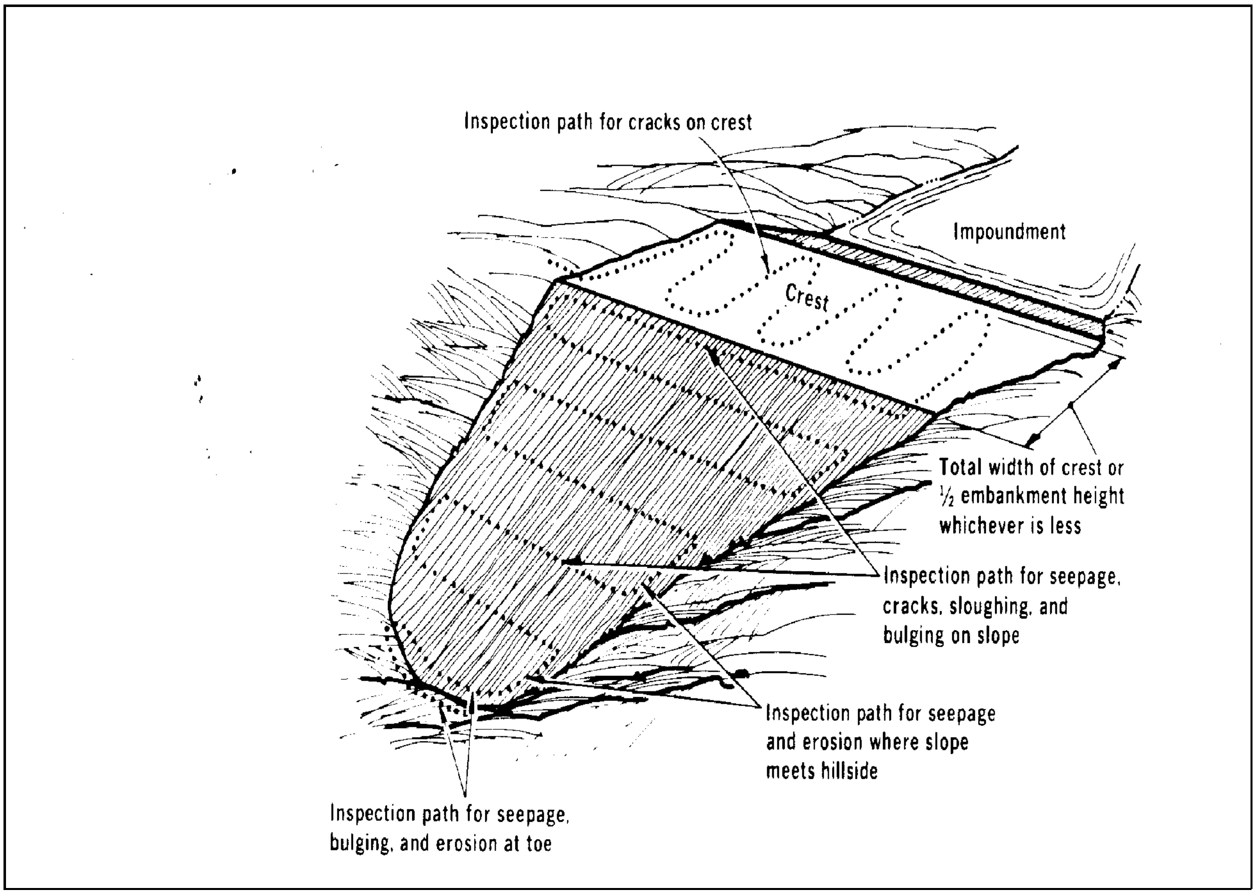


FIGURE 32
View of embankment showing inspection routes

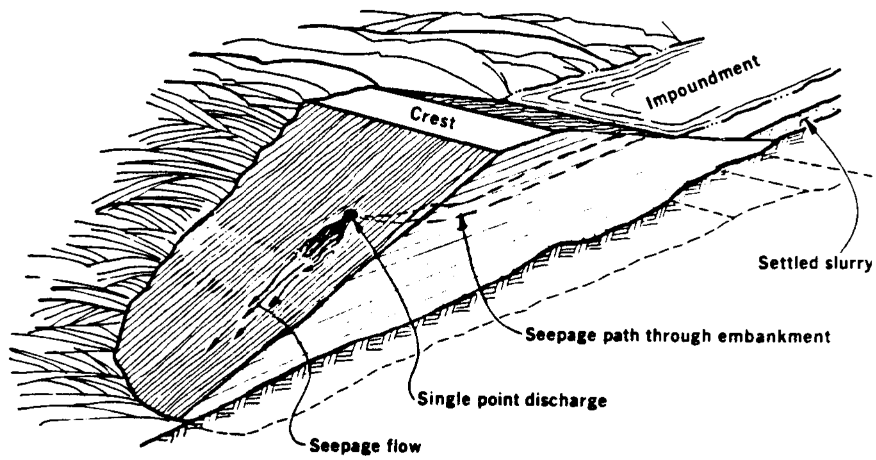


FIGURE 33
Point source seepage

the occurrence of a heavy storm when the pool level is high. However, to avoid confusion between surface runoff and seepage, the inspector should visit the site one to two days after the rain has completely stopped. The most critical seepage conditions include the following:

1. <u>Seepage Flows from Underdrain Pipes</u> -

Often seepage through an embankment is anticipated, and a drain will be placed within the structure during its construction to collect the water before it surfaces on the slope face. A perforated pipe may be placed within the drain to collect, control and discharge the water away from the slope. The inspector should become familiar with the location of any underdrain pipes exiting from a slope. Any damage due to crushing, clogging or corrosion should be reported.

2. <u>Seepage Flows at Isolated Points</u> -

Seepage through an embankment may be localized at a single-point source which then flows down the slope to the embankment toe. As shown in Figure 33, this type of seepage is detected by watching for movement of water and tracing it up the slope to its source.

Another important place to check for seepage is along the outside of any decant or spillway pipe which passes through a dam. If the pipe was not properly installed, this area can provide a path for uncontrolled seepage and internal erosion of the dam.

3. <u>Seepage in Abutment Areas</u> -

This type of seepage is often undetected because surface runoff is collected in this area, disguising seepage points. Abutments should be inspected during dry periods when surface drainage is not present. Water flowing along the edge of a slope should be traced upslope to determine its source.

4. <u>Seepage Emerging over a Widespread Area</u> -

When small seepage points spread out over a large area, their source is difficult to detect because the flow at any one point is too small to cause a traceable uphill pattern. Indicators of this type of condition can be change of color, soft areas, and changes in vegetation. The unusual height or thickness of vegetation may indicate that the area is being irrigated by seepage. Areas where vegetation has died may also indicate seepage with a high acid content. Many times seepage is easier to locate in the winter, when the seeping water melts snow more quickly than on adjacent drier areas. Often when there is no snow and very cold temperatures, seepage can cause a buildup of ice on the slope surface.

5. Changes in Seepage -

A major inspection aim is not only to locate the existence of the above types of seepage, but also to compare their volumes and appearance from one inspection to the next. Any changes in the character of the water discharging from a seepage source, such as clear water becoming cloudy and discolored, or transporting dark particles, as well as an increase or a reduction in the amount of seepage, or the presence of new seepage areas should be noted, evaluated and reported. It is good practice for companies to identify seepage areas using flags or stakes so that changes in the areal extent can be readily detected.

Photographs of seepage areas with any noted changes are very valuable records of conditions at the time of the inspection and can record conditions that are otherwise difficult to describe. Placing an object of known size, such as a book or hardhat in the photographic field adds relative scale to the picture. An inspector should keep notes of seepage conditions for each facility in order to better identify any changes.

D. Slope Movement

When stressed conditions are being created in an embankment that could ultimately result in a major slope failure, small movements usually occur long before a larger, more observable failure. A very important part of the slope inspection therefore involves locating any of these smaller slope movements. While signs of minor movement do not necessarily mean that failure is imminent, they should be technically evaluated as quickly as possible. Signs of movement, that should be carefully noted, include:

1. Cracks on the Embankment Crest -

The total width of the crest or distance equal to one-half the total height of the embankment (whichever is less) should be checked for cracking. The appearance of cracks which can vary from hairline openings to openings of six inches or more should be reported immediately for further technical evaluation. Hairline cracks may be an indicator of minor movement due to embankment settlement or surface weathering. As the width of a crack increases and begins to show signs of vertical displacement (scarp), and/or if cracks progressively appear farther back from the edge of the slope, the potential for the occurrence of a failure increases (Figure 34). Such conditions should be brought to the attention of the owner's representative and the District staff. The owner should also be requested to leave such cracks exposed until they are evaluated by a specialist. It is good practice for the company to mark the extent of any cracks, such as with stakes, so that it can be determined whether they are stable or if movement is continuing to occur.

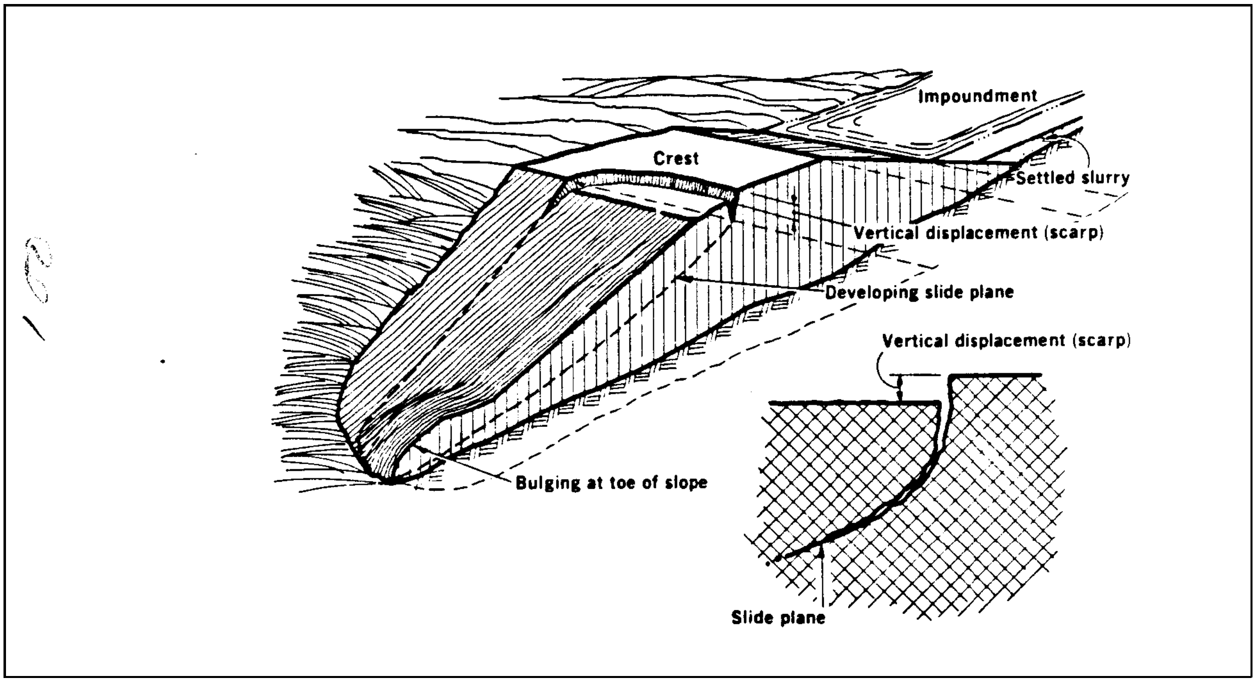


FIGURE 34
Cracks on refuse embankment with vertical displacement of material (scarp)

2. Cracks on the Embankment Slope -

Normally, such cracks will be near the top of the slope, although they can occur at any location. Vertical movement can indicate the initiation of a large slide plane, which could move more rapidly at any time. The existence of many small, short cracks, at several levels down the slope may indicate a slow or creeping movement which is less likely to move rapidly (Figure 35). A description of the number, length and location of all observed cracks should be reported immediately by the inspector.

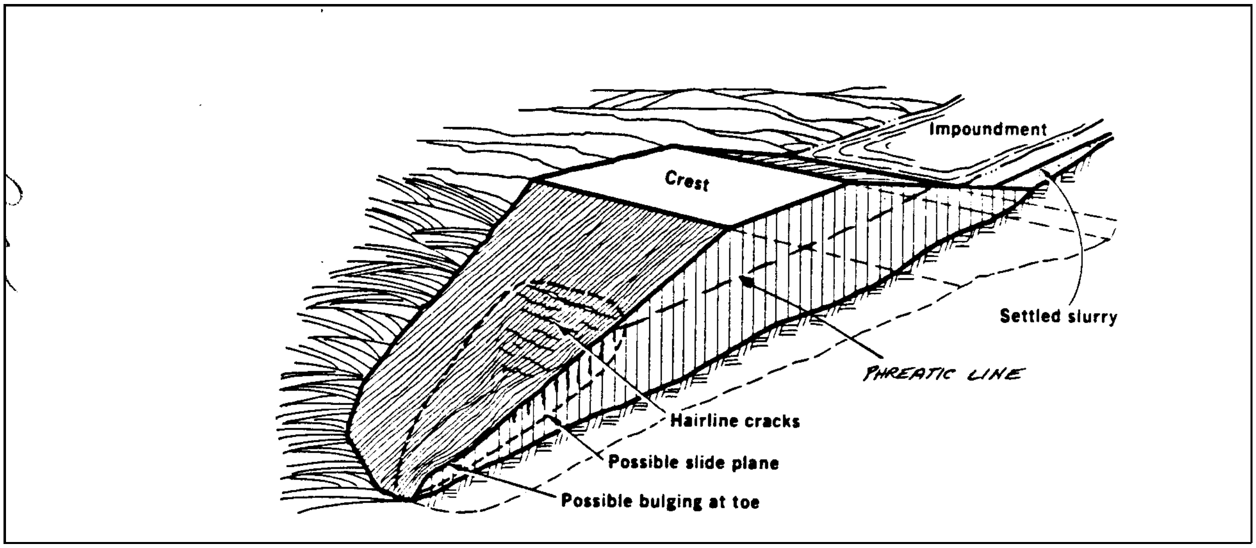


FIGURE 35
Series of hairline cracks on embankment slope indicating slope movement

3. Bulging -

When a large crack is observed, it indicates that a portion of the slope has moved. This movement usually produces a bulging of material at the bottom of the slide area. A bulging condition is often easier to detect than a crack, which may be disturbed and disguised by ongoing operations of the embankment surface. The most frequent bulge location is at the toe of the embankment where the slope meets the foundation (Figure 35). However, bulges can also occur in the middle of the slope or downstream from the toe in the foundation material. When bulging at any location is observed, the inspector should walk directly up the slope from its location to try to locate a corresponding crack at the top of the slumped area. The accurate location of both conditions is very valuable to any subsequent technical review.

4. Surface Sloughing -

One final type of sliding that has less initial importance to safety, but which can progress to a more critical condition if left uncorrected, is a shallow surface movement of a small area on the slope. This type of movement most frequently occurs on slopes during the spring thaw period. Similar movements can often be observed along spillway cuts during the first several spring thaws after their construction.

In addition to noting the presence of any cracks, bulges or surface movement of material, the inspector should also describe the approximate width of each crack and its length, record the size of any bulging, record the overall size of any surface displacement, record the location of each of these signs of instability on the sketch of the embankment slope, and describe any observed relationship between seepage areas and bulging, cracking or surface movement.

E. Erosion

Minor surface erosion is a typical condition on most slopes before vegetation is established and final drainage ditches are constructed. While such conditions should be noted and brought to the attention of the owner for correction, they are not serious and are not a cause for immediate safety concern. Severe erosion that cuts deep gullies on either the slope surface or at the abutment can be serious. This type of erosion can become much worse during a single rainstorm. When a gully becomes sufficiently deep, support to the adjacent embankment is lost and major sliding or a total collapse can occur.

Any time an area of deep erosion is observed, its location should be noted and the inspector should attempt to determine the source of water which is causing it. If the cause is not obvious, the inspector should determine if major seepage is occurring in the zone being eroded. Zones of seepage are normally more susceptible to erosion because of their water-induced softness.

DOWNSTREAM FOUNDATION CONDITIONS

In addition to the embankment surface conditions, inspecting the foundation areas immediately downstream from the embankment is also essential to determine whether or not undesirable conditions may be developing. An example of how important foundation inspection can be is illustrated by the dam failure at Saunders, Logan County, WV (Buffalo Creek). Post failure studies indicated that instability began along a slide plane through both the embankment slope and the downstream foundation material. It is probable that detailed inspection of this facility several hours before the failure (and possibly months before) would have discovered evidence of cracking on the embankment slope, and bulging of the foundation material for a short distance downstream from the toe of the slope. Also, the inspection might have revealed soft, wet areas or seepage discharging from the foundation. Early detection of such conditions by skilled observers can prevent similar failures in the future.

The inspection of the downstream foundation conditions is in many ways similar to the investigation of embankment slopes. However, downstream inspections are limited to locating and describing seepage flows or possible boils, foundation movement such as bulging indicated by unnaturally tilted vegetation, and severe erosion. Figure 36 shows the type of route that should be taken to properly inspect downstream conditions. This path will depend upon access, configuration of the toe, and the topography of the foundation. The following can be used as a general guide for conducting the foundation inspection.

Walk along the entire toe of the slope at the deepest portion of the embankment. Walk in a zigzag pattern between the toe and about 100 feet from the toe at the

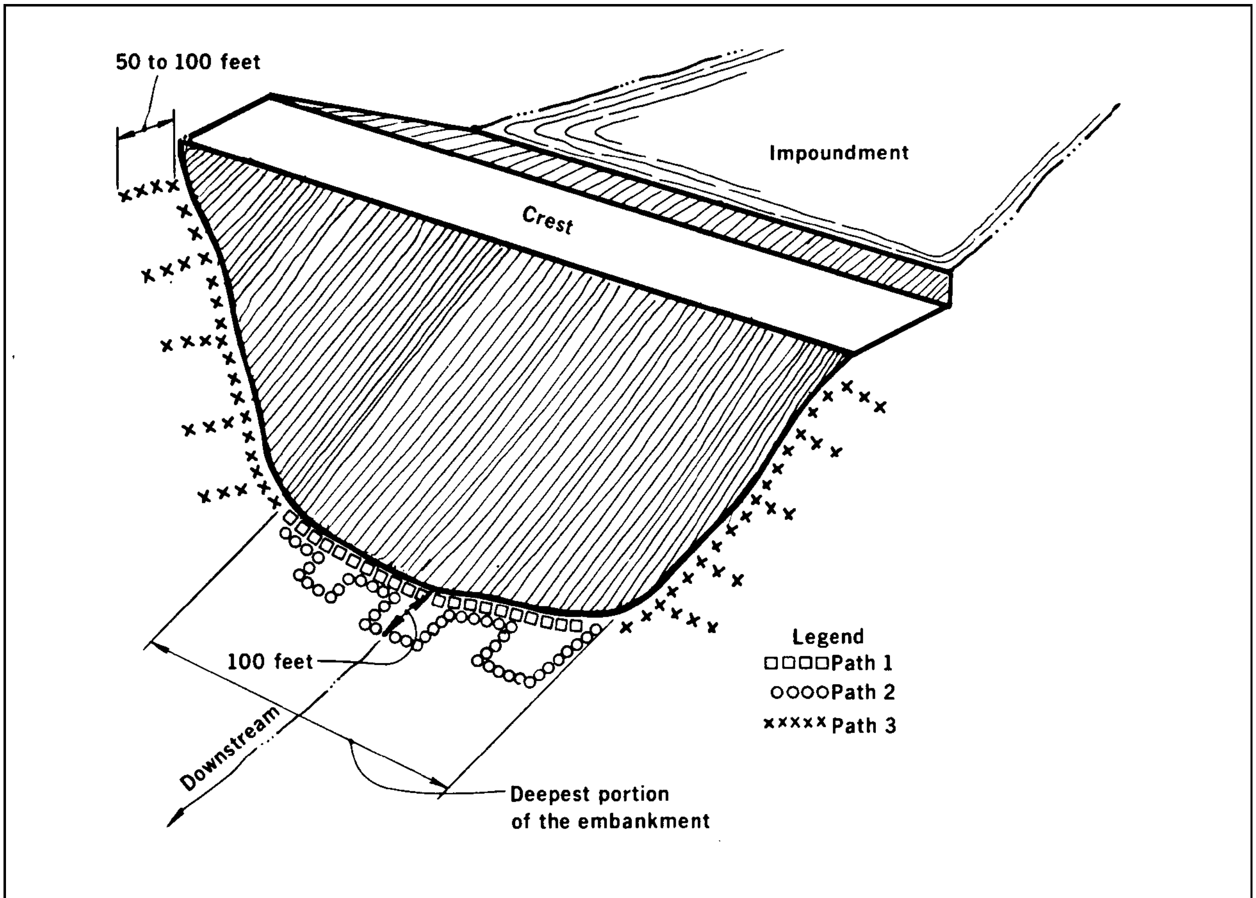


FIGURE 36
General guide for foundation inspection

deepest portion of the embankment. Walk along the natural slopes or abutments. During this part of the inspection, the inspector should occasionally walk parallel to the natural slope away from the embankment up to a distance of 100 feet to observe conditions on the hillside. Just as with the inspection of embankment slopes, any important observations should be located on a plan view drawing or a simplified plan view sketch.

A. Seepage

Seepage from downstream foundation areas is usually more common than seepage on the embankment slopes. This is due to the fact that the internal structure of an embankment can be better controlled during construction to minimize future seepage through the embankment. Subsurface and foundation conditions are more difficult to modify and therefore seepage may occur more readily in these downstream foundation areas, as shown in Figure 37. Seepage from the impoundment area that flows through foundation material and either emerges at the toe, or some distance downstream, is more critical than seepage from a controlled and low phreatic line emerging on the embankment slope. In instances where foundation seepage occurs, stability of the embankment can be significantly threatened and the potential for eventual failure is greater. Conversely, if seepage is caused by natural groundwater flowing through hard-rock fractures beneath an abutment, the condition may not have any effect on the stability of the embankment. The inherent stability of the rock will keep conditions from deteriorating.

Another serious indication of downstream foundation seepage is the formation of boil-like features in the saturated areas. These distinctive features have the appearance of small volcanos and normally occur in the flatter portion of the downstream valley floor. A special inspection effort must be made to detect this type of seepage when it occurs under water in either a shallow stream or in a ponded area.

The most critical aspect of inspecting for downstream foundation seepage is to not only locate the existence of the seepage flows, but also to compare the amount and appearance of such flows from one inspection to the next. Any significant changes should be brought to the attention of the district staff.

B. <u>Foundation Movement</u>

Simultaneous with the examination for seepage zones, an inspector should look carefully for any signs of downstream foundation movement. If this movement is linked with slope movement, it will usually occur in a horizontal direction away from the slope, or can be a bulging movement, where the foundation material is pushed upwards. Because most downstream foundations do not initially have a smooth surface, recognizing this type of movement can be difficult. However, some of the more common indicators of foundation movement are sharply rising ridges that can vary in height from six inches to several feet and run parallel to the toe of the slope, or the unnatural tilting of trees or other vegetation, as shown in Figure 38.

When these signs are observed, the inspector should then investigate the toe and slope for corresponding cracks, as well as other signs of movement that appear

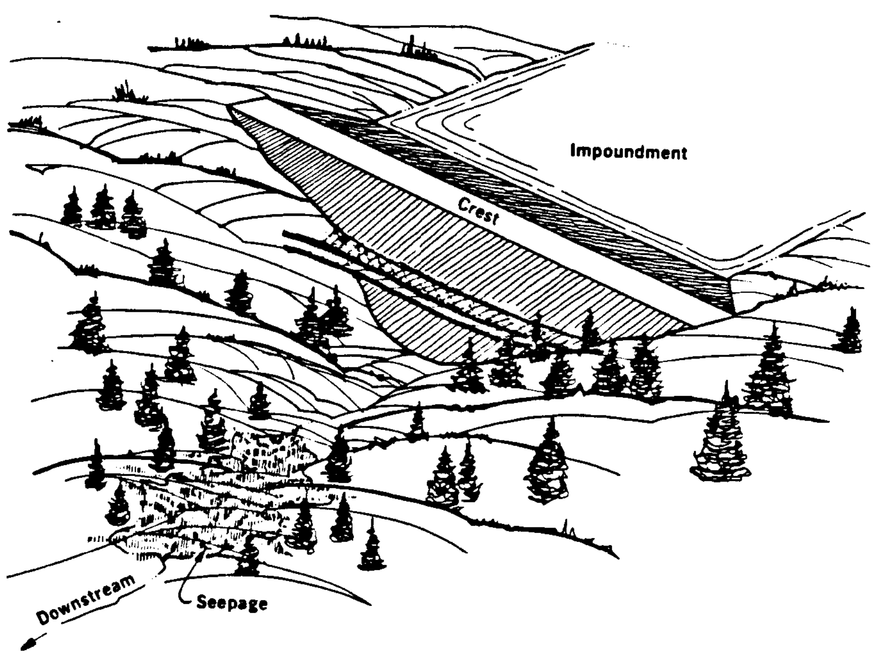


FIGURE 37
Seepage emerging downstream

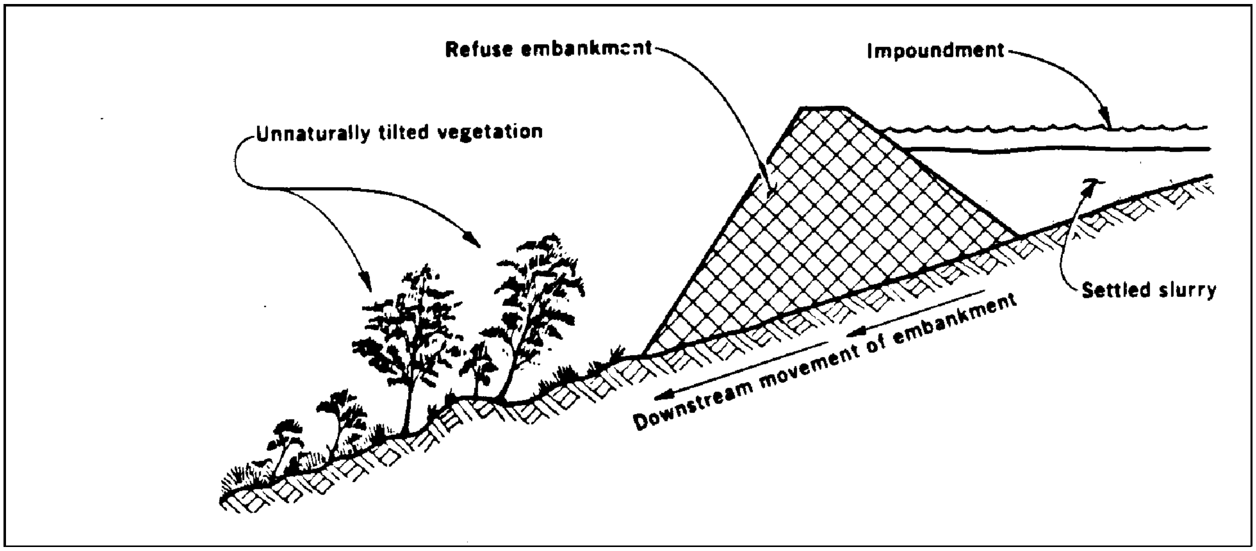


FIGURE 38
Embankment movement forming parallel ridges
and tilting vegetation on valley flow

to be related to areas of seepage or erosion. All signs of movement should be noted and reported.

C. Erosion

Erosion conditions of the undisturbed downstream foundation areas are usually not critical unless undercutting of the toe occurs. This condition may be caused by abnormally large stream flows or uncontrolled discharge of hydraulic structures.

SLURRY IMPOUNDMENTS

The disposal of fine refuse as a liquid slurry into an impoundment normally requires the construction of a dam. Examples of these types of facilities are discussed in Chapter 2 of this Handbook. A dam requires a great amount of care during its design and construction because of the large volume of water that can be retained, presenting a potential hazard downstream. Normally, dams require a greater amount of attention by the inspector than do refuse piles.

Most signs of potential impoundment problems are observed on its downstream slope, in the foundation area downstream from the structure, along the spillway, and in the vicinity of the decant system. The following discussions cover additional areas of concern that the inspector should evaluate during the inspection of an impoundment.

A. Water Level

Water level control during normal operating conditions is usually provided by a decant installed to discharge excess water to a predetermined level. Significant increases in the water level from one inspection period to the next, during which time there were no large rainfalls, may indicate that the decant is clogged or otherwise malfunctioning. The opposite may also occur, and a sudden drop in the water level between inspections may indicate the presence of a seepage problem.

During an unusually heavy storm, the water level in most impoundments is controlled by an emergency spillway that discharges all water above the invert of the spillway. The decant system drains the remaining water to its normal impoundment level. An inspector is usually not present to evaluate the functioning of the hydraulic structures during a storm. However, an inspector should determine if the water level remains unusually high for an abnormal period after a storm.

B. Existing Embankment Freeboard

The freeboard of an embankment is defined as the "vertical distance from the water surface of the impoundment to the lowest point on the embankment crest," as shown in Figure 39. The amount of freeboard required for any given impoundment varies with the design of the dam. If the freeboard distance is smaller than it should be, there is a danger that the dam may be overtopped and may fail during a large storm.

The amount of freeboard is particularly critical for slurry impoundments because the water level increases over time as slurry is added. This continuing increase of the impoundment level requires periodic increases in the dam's height. If the rate of slurry disposal is greater than originally planned, or if the dam height is not raised at the proper time, the freeboard can become less than is needed to temporarily store runoff from a heavy storm. If the actual freeboard is less than the requirements on the approved plan, appropriate action should be taken.

C. Slurry Discharge Location

In order to minimize seepage related stability problems at an impoundment, it is desirable to keep the water portion of the impounded fine refuse slurry as far away from the retaining dam as is practical. This is accomplished by locating the slurry discharge line near the upstream face of the dam.

As the slurry is pumped into the impoundment, the heavier, more coarse particles will settle out of the slurry near the face of the dam. The water and finer material are forced upstream and away from the face of the dam. However, the slurry should not be discharged directly onto the upstream embankment slope, as this can cause erosion and the structure may be substantially weakened.

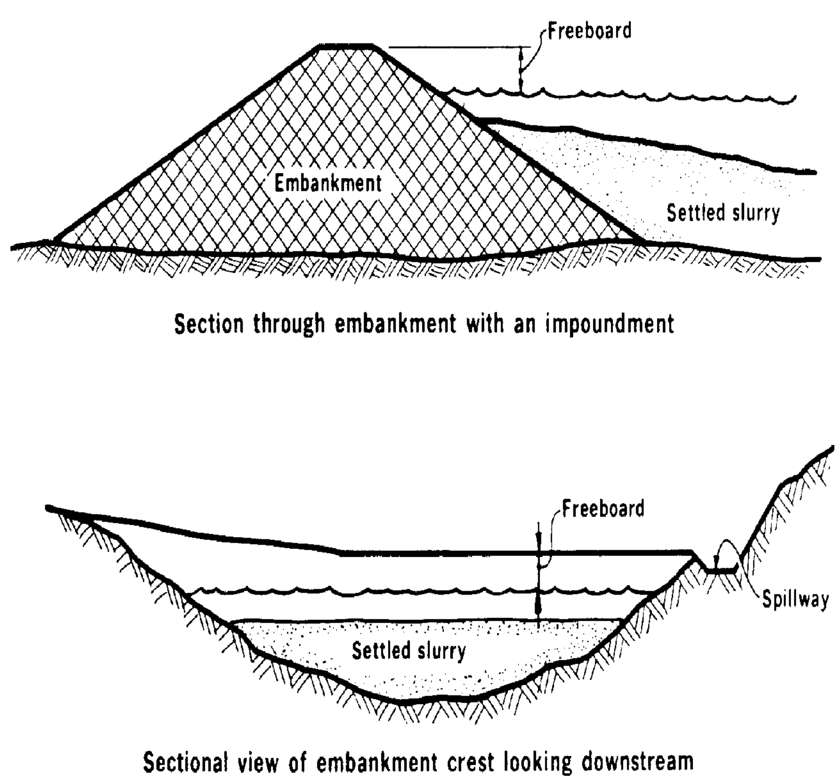


FIGURE 39
Typical freeboard relationship

D. Embankment Condition

An inspector must investigate the upstream slope of the dam as carefully as the downstream slope. Although seepage is not a concern on the upstream slope, sliding and sloughing movements and erosion are. Observable signs of slope movement are essentially the same as those previously described in Section E-4 of this chapter. Bulging at the bottom of the sliding material may not be evident on upstream slopes because the lower portion on the embankment slope (the upstream toe) is normally covered with fine refuse material.

Gully erosion, due to storm runoff from the dam crest or from adjacent hillsides, can also become a matter of serious concern on the upstream slope of the dam. If not detected and controlled, this type of erosion can eventually cut completely across the dam crest, and subsequently reduce the freeboard.

E. Exposed Fine Refuse Surface

If an impoundment has been properly constructed and its drainage facilities are functioning, the exposed surface of settled fine refuse in the impounding area should be uniformly sloping away from the slurry discharge point. Visible sumps or sink holes occurring on the fine refuse surface may be an early indication that fines are being transported by seeping water through the embankment or foundation. If the condition goes uncorrected, these sink holes can enlarge rapidly as more particles are transported through the structure. The downstream slope and foundation area should be examined for a seep which shows evidence of transported fine refuse material. If this condition, called piping, has developed, it will have serious implications if not promptly corrected by the owner. Any sudden appearance of sink holes that were not present during previous inspections should be brought to the immediate attention of the District specialist.

HYDRAULIC STRUCTURES

Drainage facilities include all pipes, channels and ditches that are excavated, constructed or installed to convey water past an embankment. A decant or spillway failure during a very heavy storm could cause the water level to rise up and overtop the dam. Once a dam is overtopped its failure and release of the reservoir is likely. So an inspector needs to be familiar with drainage structures and be able to recognize conditions that either impair or destroy their proper operation.

A. Open Channel or Culvert Spillways

The purpose of a spillway is to safely discharge heavy storm flows from an impoundment. Most spillways are constructed by excavating a large channel in the natural hillside around the abutment of the dam. Some spillways are constructed by placing large diameter pipes through the embankment. Whatever the type, it is important that the size of the spillway, and the vertical distance between the inlet and the crest of the dam, is at least as large as the approved plan specifications. Otherwise the spillway will not pass the intended flow and the dam could fail by overtopping. Some of the inspection requirements for an open channel spillway are:

- Is there blockage of the channel due to debris or from sloughing or sliding of material? If so, then the channel should be cleared. If it appears that blockage may be a chronic problem, it should be brought to the attention of the company and the District staff for further evaluation.

- Are areas, susceptible to erosion, adequately protected? Areas with sharp bends or steep grades are particularly prone to erode. If the channel, or a portion of it, is not cut into competent rock, then erosion protection, such as a lining of concrete, riprap, or grass, is normally required. The type of lining called for depends on the velocity of flow for which the channel is designed and approved for.

- Is the concrete liner cracked, badly spalled, or displaced? Are the weep holes open so that the water pressure under the liner might be dissipated? Has riprap been washed away, exposing underlying soil to erosion? Is the rock dis- integrating due to weathering? Any other signs of sign- ificant erosion or evidence that the channel may not be able to contain the flow.

- Does the channel outlet extend far enough downstream to safely discharge the flow past the dam? If the spillway outlet channel is not constructed to proper depths and grades as called for in the approved plan, a breach or overflow of the channel could result in the storm water discharging onto the downstream slope of the impounding structure.

In addition to the inspection items listed above, an inspection of a culvert spillway should include the following:

- Is the pipe entrance free of debris? Is a properly designed and maintained trash rack present to ensure that the pipe can not be blocked; and

- Has the pipe been damaged in any way? This would include crushing, corrosion or cracking due to uneven settlement. These items could reduce the capacity of the pipe during design flows.

B. Decants

The most common decant system consists of a pipe installed beneath the embankment with a vertical or sloping inlet section which has an opening at the desired water level (see Figure 25, Chapter 3). Because of the continuous disposal of fine refuse, the inlet pipe must be periodically raised to accommodate the rising water surface. However, due to the important relationship between the normal pool level and the required storm capacity of the impoundment, the inlet pipe cannot be arbitrarily raised. If the pipe appears abnormally high, for instance higher than the spillway invert, then this condition must be corrected.

It is very unlikely that an inspector will be present during a major storm to observe decant performance. It is therefore important that the normal operation of a decant be closely observed. Decants at impoundments provide the following three important functions of which the latter one is usually the most critical with regard to safety. A decant routinely discharges clarified water from the impoundment, it discharges impoundment inflows occurring as a result of small rainstorms that cause relatively small increases in the elevation of the water surface, and it removes large volumes of short-term, temporarily stored water that inflows into an impoundment as a result of unusually severe storm activity. Decant inspection should include the following:

- Clogging of the decant inlet or a portion of its pipe is a common cause of decant malfunction. The intake should be equipped with a trash rack designed to prevent large pieces of floating material from entering the pipe. Trash racks need to be cleaned periodically and possibly also need repair.

- Because of the small size of most decant pipes, and because they are buried, an inspector can observe only the inlet and outlet areas. Therefore, the inspector should examine these areas very carefully for any signs of cracking, crushing, corrosion or other indications of distress which may be occurring in other portions of the decant.

- The decant outlet channel should provide for the safe discharge of flow away from the dam. The outlet channel should be inspected for clogging, deterioration or other maintenance problems.

C. Pumps

Some impoundments have pumps to maintain normal water level and to remove storm water. If pumps are being used, the inspector should observe the general appearance of the pumps and the power source, determine if the water level is being maintained as specified in the approved plan, and inspect the pump discharge point to ensure that it cannot cause erosion problems.

D. Diversion Ditches

Diversion ditches vary in size, location, configuration and purpose. Some diversion ditches are an integral part of the overall design of an impoundment. However, most diversion ditches are installed to keep storm water away from construction areas. During the inspection, observations for the following conditions should be made:

- blockage of a ditch due to heavy growth of vegetation, sloughing of side slope material or accumulations of debris;

- excessive erosion;

- discharge points causing erosion problems in critical areas; and

- deterioration of the channel lining.

INSTRUMENTATION

Various types of instrumentations are used to monitor the long-term behavior of an embankment. This instrumentation can be placed either on the surface of a structure or within its interior, depending on the nature of the instrumentation and the monitoring requirements. Some of the above types are discussed in the following paragraphs. An inspector should become familiar with these instruments and their location on a dam.

A. Piezometers

In its simplest form, a piezometer is a section of pipe installed vertically in either an embankment, adjacent hillside, or foundation area, which allows the depth to the saturation level or groundwater to be measured. The piezometer pipe, with small holes or slots at the bottom end, is inserted into a drilled borehole and the space around the pipe is backfilled with sand or gravel. The upper portion of the borehole is then sealed with clay or cement to keep surface water from infiltrating around the pipe (Figure 40). The distance down to the water is normally measured by lowering a probe which completes an electrical circuit when it contacts the water in the pipe. Some types of piezometers, such as pneumatics, consist of cells and small size tubing which are buried in the embankment or foundation. The tubes are brought through the fill and when a gage is connected to them the water pressure at the cell can be measured and recorded.

The stability of a dam is directly related to its saturation level; acceptable piezometric readings are determined during the design and are indicated in the

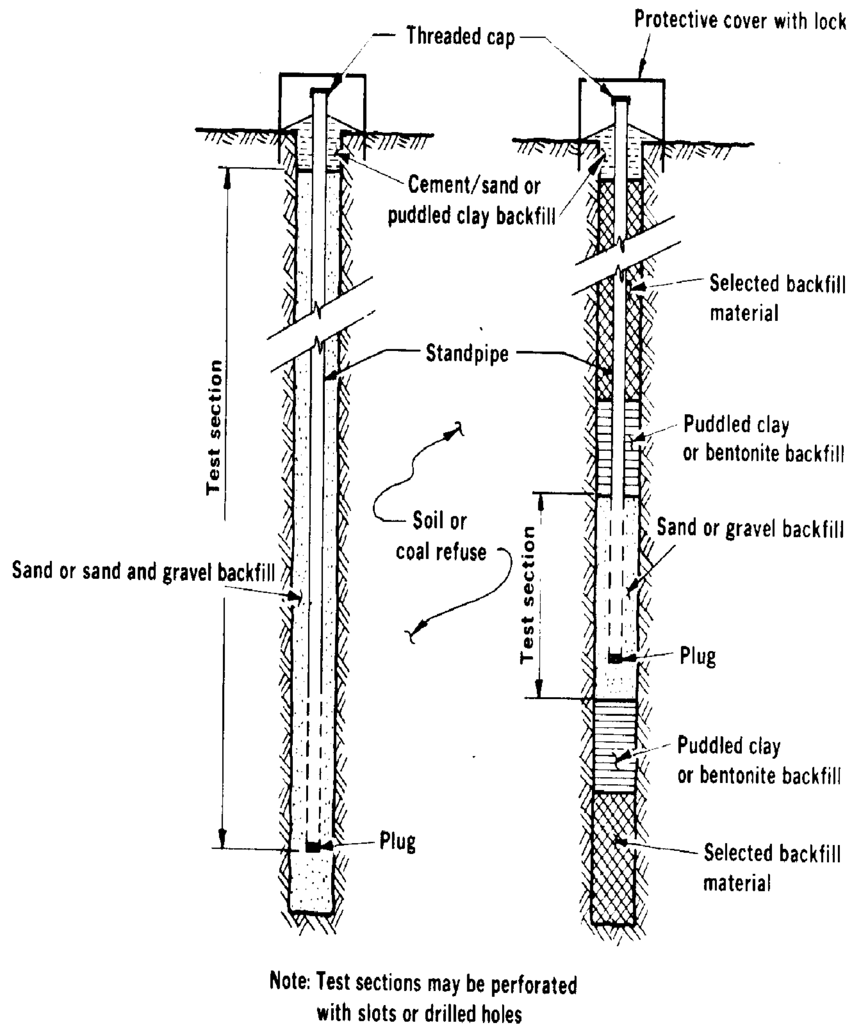


FIGURE 40
Open standpipe piezometer

approved plan.

As with other types of instrumentation, an inspector is not responsible for properly locating and installing piezometers. However, once these instruments are in place, the inspector should periodically inspect them to ensure that no conditions exist that interfere with their operation. Such adverse conditions could include the following:

- The operation of construction equipment next to or in the vicinity of the piezometer casings, which might disrupt or destroy the proper functioning of these instruments. In active work areas all instrumentation and casings should be protected by a substantial guard.

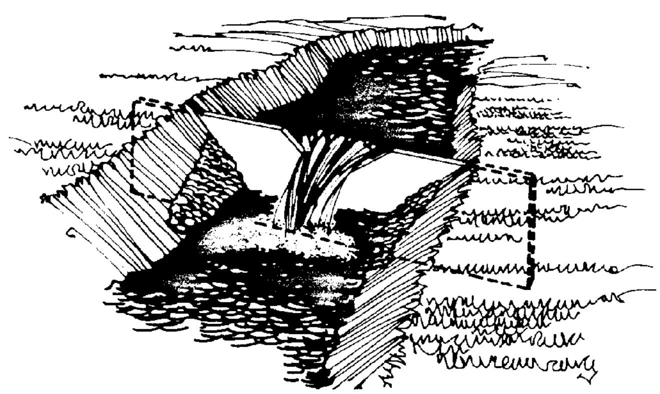
- The absence of a protective cap, due either to vandalism or oversight, could lead to either accidental or willfull filling of the piezometer pipe.

- Conditions where surface drainage or periodic runoff can enter the borehole or the piezometer pipe itself; the surface area around the piezometer should be sealed with clay or cement.

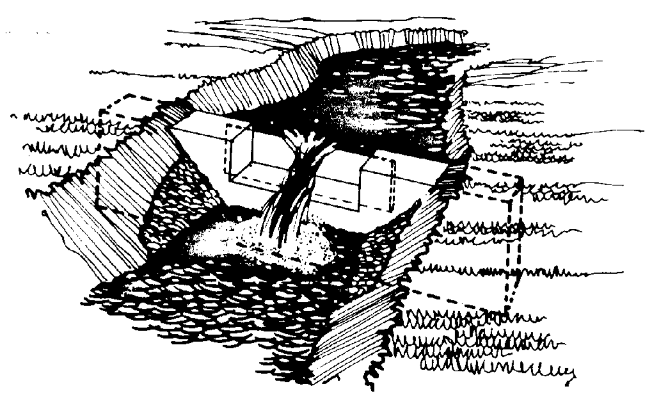
B. Weirs and Underdrain Pipes

The monitoring of surface water flows or seepage discharges can provide critical information in evaluating the safety of a dam. These discharges can be measured as they emerge at one particular point source beyond the toe of the structure. The use of a V-notch or rectangular weir can be helpful in measuring discharges (Figure 41). A weir is calibrated so that the discharge over it can be determined by measuring the head of water just upstream of the notch. The records kept from such measurements can be very useful in the overall evaluation of the structure by indicating, for example, whether a drain is functioning properly.

All surface flow instrumentation must be properly maintained. Any cause of weir malfunctioning should also be reported. These causes can include such things as the deterioration of weir material, flow bypassing the weir due to erosion around or under the weir, damage due to excessive flows, obstructions, or construction activity, which can cause gradual buildup of sedimentation behind a weir and destroy its usefulness.



a. Temporary installation



b. Extended life installation

FIGURE 41
Illustration of typical
weir installations

In the case of pipe discharges, an inspector should note and report any pipe deterioration, clogging or other type of obstruction caused by either natural conditions or nearby construction activity.

C. Survey Monuments

Survey monuments can be constructed in a number of ways that vary from simply driving a reinforcing rod into the embankment to constructing more permanent type monuments of poured concrete with protective covers (Figure 42). An inspector should be aware of their location, and any construction or machinery activity in the vicinity of these monuments that could disturb or destroy them.

D. Other Instrumentation

Casings or wells in which inclinometers are used to measure internal horizontal movement, settlement gauges used to measure vertical movement within an embankment, and thermocouples to measure temperatures within the embankment can be used for specific problems.

ADDITIONAL CONSIDERATIONS

Other aspects of a refuse disposal site which an inspector should be familiar with include the potential for the refuse to burn, and the possibility of mine subsidence.

A. <u>Burning within a Refuse Structure</u>

Improper construction of a coal refuse facility can create conditions that encourage rapid oxidation of the pyritic materials, a corresponding temperature buildup and eventual spontaneous combustion and burning of the interior refuse material. This can occur due to inadequate compaction and/or the improper mixing of larger rock with the refuse which allows large volumes of oxygen to infiltrate the refuse structure.

The presence of burning in an active refuse facility should be a critical concern to an inspector. The continued use of such a facility is usually permitted, provided the burning can be confined to a small area of the embankment and no new refuse is placed in the vicinity of the burning. However, this decision is made by the District specialist, not the inspector. When inspecting a burning refuse

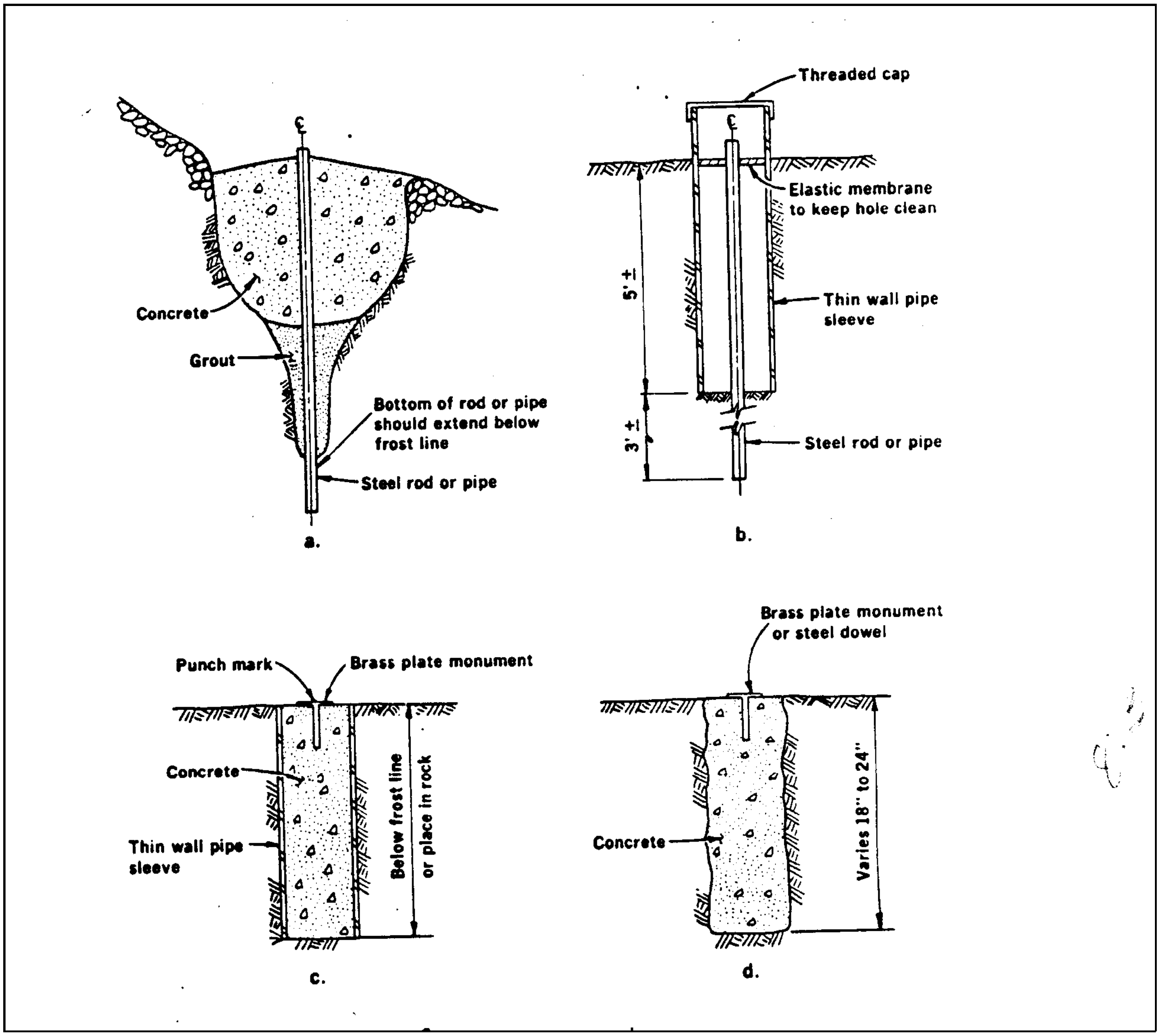


FIGURE 42
Survey monuments

facility, an inspector should be particularly concerned with

- Any changes in the extent, location or character of the burning area. If it appears that the burning has increased or diminished in size or intensity since the previous inspection, the inspector should describe this change on the Periodic Inspection Form, and report it to the District specialist.

- The unapproved placement of refuse material over the burning portion of the facility. If such practices are observed by the inspector, the District specialist should be notified immediately. An appropriate description of this activity should also be made on the inspection form.

- Any unauthorized efforts to extinguish the burning area. Some extinguishment procedures can seriously reduce the stability of the refuse structure. For this reason, no firefighting actions are permitted unless they are performed in accordance with a plan approved by the District Manager.

B. Mine Subsidence

In some cases there may be underground or auger mining near or under a refuse disposal facility. The occurrence of subsidence or the development of a sinkhole under or near an impoundment could have a serious effect on its safety. An active underground mine could be endangered by an inundation of water. Any signs of mine subsidence near or on a dam or refuse facility should be reported to the District staff for further evaluation.

CHAPTER 5 - IMPOUNDING STRUCTURES SAFETY DESIGN PROCEDURES

The following material should be used by MSHA personnel who review active or proposed impoundment design plans in accordance with the impoundment plan approval process. MSHA intends to periodically update and expand the information as it is needed.

Information in this Chapter that was obtained from MSHA Procedure Instruction Letters, may be acquired by coal mine operators or designers of coal mine impounding structures, by ordering Informational Report (IR) 1206, titled Presentations from the 1992 Coal Mining Impoundment Informational Meeting.

A. Compaction Specification

1. Proper compaction of embankment material is one of the most important elements in the construction of a safe dam. As stated in Engineering and Design Manual - Coal Refuse Disposal Facilities, E. D'Appolonia Consulting Engineers, Inc., 1975, "Any soil placed as a constructed structural fill, including coal refuse embankments, is normally compacted to increase density and shear strength and to decrease compressibility and permeability." Testing has shown that a small change in the density of coarse coal refuse can have a significant impact on some of its properties.

   Compaction specifications need to place acceptable limits on the minimum dry density, the range of placement water content, and the maximum lift thickness. In arriving at these specifications, it is prudent that the recommendations and practices of authoritative and experienced dam builders, referenced in Item 2, should be used for guidance. The following recommendations are made for the structural fill portions of impounding structures:

   a. Material should be compacted to at least 95 percent of the maximum dry density as defined by the standard Proctor test, with the placement water content not exceeding the range of -2 to +3 percent of optimum.

   b. In compacting coarse coal refuse, the lift thickness should not exceed 12 inches. When fine-grained soils are used for embankment construction, lift thickness should not exceed 8 inches.

   c. For materials where the Proctor moisture-density relationship does not apply, specifications should be based on relative density test values.

   Less stringent compaction specifications than those cited above would not generally be consistent with current, prudent engineering practices. Plans with such specifications cannot be recommended for approval unless a detailed technical justification, which demonstrates that the proposed practice would have no adverse effect on the safety of the dam, can be provided by the designer. The designer would need to show through testing and analyses that all potential problems, including settlement, cracking, piping, instability, stratification, and seepage, have been taken into account in the design and that compensating design features have been incorporated. It should be noted that less stringent compaction specifications can generally be used in areas that can be shown to be "non-structural" portions of the dam.

2. Some pertinent references on compaction specifications are as follows:

   a. Naval Facilities Engineering Command, NAVFAC DM-7.2, May 1982, Table 4, page 7.2-46. For earth dams greater than 50-feet high, the required density is 95 percent of modified Proctor, moisture limits of -1 to +2 percent of optimum, and 12($\pm$)-inch compacted lift thickness.

   b. Corps of Engineers, Earth and Rock Fill Dams, EM 1110- 2-2300, March 1971, pages 5-13. "Selection of design densities, while a matter of judgement, should be based on the results of test fills or past experience with similar soils and field compaction equipment. The usual assumption is that field densities will not exceed the maximum densities obtained from the standard compaction test nor be less than 95 percent of maximum densities derived from this test."

   c. Bureau of Reclamation, Design of Small Dams, Third Edition, 1987, Table E-1, page 657. Cohesive soils controlled by Proctor test having 0-25 percent plus No. 4 fraction by weight should have a minimum acceptable density of 95 percent and a desirable average density of 98 percent; and 26-50 percent plus No. 4 fraction by weight should have a minimum acceptable density of 92.5 percent and a desirable average density of 95 percent. More than 50 percent plus No. 4 fraction by weight should have a minimum acceptable density of 90 percent and a desirable average density of 93 percent. These percentage densities are based on the minus No. 4 fraction and limit moisture content to -2 to +2 percent of optimum. Permeability testing should be performed on cohesive soils that contain more than 50 percent gravel and are used as a water barrier.

   d. S. K. Saxena, D. E. Lourie, and J. K. Ras, Compaction Criteria for Eastern Coal Waste Embankments, Journal of Geotechnical Engineering, Volume 110, No. 2, February 1964. "Recommendation - Based on the findings of this study, it is recommended that coarse coal refuse, typical of eastern United States coal regions, be compacted near the optimum moisture content to a density greater than 95 percent of maximum dry density determined in accordance with ASTM D-698. Compacted lifts should not be greater than 1 ft. (0.3m) in thickness."

B. Graded Filters

There are several axioms that apply to dam design, construction, and operation. First, all dams leak. Second, the leakage must be controlled. In concrete dams the expected seepage is accommodated through the inclusion of collection galleries, whereas granular drains are commonly employed to control seepage in earth structures. When including a drain or filter in an earth structure, the designer should always consider material compatibility. That is, the granular material serving as the drainage medium should be much more permeable than the material (base soil) from which the seepage flowed. It should also exhibit explicit grain size grading to preclude the potential for base material particle migration. There are two major calculative methods available to determine piping potential and drain adequacy.

The first method was developed by Bertram and Terzaghi in the early 1940s and is still widely accepted. This procedure can be found in the Engineering and Design Manual - Coal Refuse Disposal Facilities as well as Cedergren's Seepage, Drainage, and Flow Nets, Sherard's Earth and Earth-Rockfill Dams, and Seepage Analysis and Control for Dams by the Corps of Engineers.

The second method was developed by the Soil Conservation Service (SCS) in their Soil Mechanics Laboratory in Lincoln, Nebraska. It became the SCS official policy on January 15, 1986, with the publication of Soil Mechanics Note No. 1, 210-VI-Guide for Determining the Gradation of Sand and Gravel Filters. After reviewing the work done by the SCS, the Bureau of Reclamation has also adopted this method of designing graded filters. A design standard was published on May 13, 1987, by the Bureau of Reclamation titled Design Standards - Embankment Dams No. 13,Chapter 5, Protective Filters.

Criteria differences exist between these authoritative sources, but both methods are well documented and widely accepted. MSHA deviates from these procedures in only one area. The criteria specify that average gradation band sieve size values should be utilized in developing sieve ratios. In each method, developers assume parallel, narrow, well defined gradation bands representative of well-controlled, manufactured granular drain material and relatively homogeneous base soils. Many filter and drain gradations examined by the Office of Technical Support personnel reveal that the bands are neither narrow nor parallel to the base material. Therefore, MSHA will continue to utilize extreme limit values in their analyses of associated gradation bands. It should be noted that, except for the deviation in the standard procedure mentioned above, all criteria listed in the method utilized should be followed explicitly.

If any other method is to be used, sufficient documentation and proof of acceptance should be submitted.

C. Reservoir Evacuation by Pumping

When pumps are used as part of the hydraulic system, prudent engineering practice must be followed to ensure adequate safety. The following discussion presents ideas that might be helpful in the design and review of a pump facility.

First, a pump system may not be used to route storm runoff through an impoundment. Second, if a pump system is the primary evacuation strategy for an impounding structure, the pump system must meet the drawdown criteria of removing 90 percent of the volume of water stored during the design event within 10 days.

Since many types of pumps are available for various functions, it will be necessary to have all pertinent design data submitted regarding the proposed pump facility. It must be substantiated with design calculations that the pumps can discharge the impounded runoff from the design storm under all possible conditions within the allowable time.

Because of the possibility of operational pump failure during the initial stages of the design storm, an impounding facility without an adequate spillway must be of sufficient size to store the runoff from the appropriate design event. A backup pump capable of meeting drawdown criteria should be immediately available in case the primary pump fails.

Upon initial installation, the pumps should be operated for a sufficient length of time to ensure proper operation of the system. Since it is possible that capacity under actual conditions will vary from the manufacturer's data, the outflow should be monitored and recorded whenever the system is tested.

The design operating criteria should include the requirement that the pump system be activated for a short time once every week to ensure that damage has not occurred within the system. It should also be required that the pump system be activated just before a forecasted storm of significant magnitude. Check valves should be installed on all pumps to prevent reverse flow that could cause damage to any pump's internal mechanism.

Due to the nature of significant storm events, electrically powered pumps that obtain their power from sources away from the immediate vicinity of the pump are unacceptable. Power lines and electrical auxiliary power sources may become inoperable during a storm. The only acceptable power source is an internal combustion engine, either coupled to the pump or as an adjacent generator specifically for the pump. The method of storage for the pump's fuel supply should be clearly presented. Since additional local, state, and federal regulations may apply to such installations, it is the mining company's responsibility to ensure that appropriate agencies are contacted and that their requirements are considered.

It will be necessary to evaluate each system on its specific design features. Therefore, the designer must submit complete design criteria, data, calculations, and all other pertinent information that will clarify the pump system design.

D. Pressure Testing of Spillway Conduits

Leakage problems have occurred in a number of pipe installations. Both infiltration and exfiltration have been observed. As a result, MSHA requires pressure testing of all pressure conduit spillways. Joints also need to be tested in some non-pressure situations where conditions are such that loss of backfill or slurry could occur due to infiltration or leakage along the pipe. For guidance on this subject, specifications from other organizations have been examined and those that appear applicable are discussed below.

The Soil Conservation Service (SCS) has two specifications; one for pressure pipe and one for non-pressure pipe. In the National

Engineering Handbook, Section 20, "Construction Specification 42: Concrete Pipe Conduits and Drains," the SCS, for non-pressured applications states that:

> Prior to the placement of concrete or earthfill around the conduit, the conduit shall be tested for leaks in the following manner: The ends of the conduits shall be plugged and a standpipe with a minimum diameter of two (2) inches shall be attached to the upstream plug. The conduit shall be braced at each end to prevent slippage. The conduit and the standpipe shall be filled with water. The water level in the standpipe shall be maintained, by continuous pumping, a minimum of 10 feet above the invert of the upstream end of the conduit for a period of not less than two hours. Any leaks shall be repaired and the conduit shall be retested as described above. The procedure shall be repeated until the conduit is watertight.

The pipe joints shall show no leakage. Damp spots developing on the surface of the pipe will not be considered as leaks.

For pressure applications, the SCS states in Engineering Memorandum-27 (Rev.)

> Conduit joints will be designed and constructed to remain watertight under maximum anticipated hydrostatic head and maximum probable conditions of joint opening . . . including the effects of joint rotation and a margin of safety where required.

A similar statement can be found in Earth Dams and Reservoirs - Technical Release No. 60. Also in Technical Release No. 60, "All conduits under earth embankments are to . . . withstand the internal hydraulic pressures without leakage under full external load and settlement.

The American Water Works Association (AWWA) suggests in their concrete pressure pipe manual that "Leakage allowances are generally specified in the range of 10-50 gallons per inch diameter per mile of pipe per 24 hours. This assigned value is intended only to give the contractor some allowance for apparent leakage, since any observed leaks must be repaired." Prior to testing, "The line should be filled at a slow rate to prevent air entrapment and should be left with a low pressure for 24 hours prior to testing. This will saturate the concrete lining and reduce the apparent leakage attributable to absorption by the pipe walls." The AWWA further suggests that "Test pressures are commonly specified as some value slightly greater than the operating pressure, such as 120 percent of operating pressures."

The U.S. Bureau of Reclamation has apparently adopted the AWWA approach with regard to field testing siphons. In Typical Specifications, Item 5.1.4, the reader can find, "After a siphon is completed, it shall be tested for watertightness by being filled with water to the elevation of the floor at the downstream end of the outlet . . . The total amount of leakage from the siphon during this 24-hour period shall not exceed 50 gallons per inch of diameter per mile of siphon." The Bureau does not address apparent leakage, but most if not all siphons designed and constructed by the Bureau are concrete.

Considering the foregoing specifications, plans should require that all pressure conduits be pressure tested to at least the expected maximum design hydrostatic pressure. The test period should range from 2 to 24 hours depending on pipe material and jointing. Joints should be visually inspected for leakage, whenever possible. An apparent leakage of 50 gallons per inch diameter per mile of pipe will be considered acceptable for concrete pipe provided that all obvious leaks are repaired. All other types of pipe, i.e., corrugated metal, smooth-wall steel, high-density polyethylene, and polyvinyl chloride should be watertight. When testing plastic pipe with water, manufacturer's specifications should be consulted to determine test duration and allowance for pipe expansion. In testing with air, no pressure loss is acceptable during testing, regardless of the pipe, because the loss cannot be measured. Where welding is required, the welder should be certified.

Pipes are normally pressure tested prior to backfilling so that any leaks can be readily repaired. Designers need to consider, however, especially for flexible pipes with mechanical couplings, that joints may not remain watertight after the pipe has been buried under fill and deflects. Plans need to address this concern.

For non-pressure applications using corrugated metal pipe (CMP), hugger bands with gaskets should be used as a minimum; dimple bands are not acceptable. Furthermore, all corrugated metal pipe should be the welded seam variety; lock seam and riveted CMP are not acceptable unless adequate leakage control measures are provided.

While the watertightness of joints is a definite concern in pressure flow situations, joint tightness may also be a concern in non-pressure flow cases. This occurs when the backfill around a pipe is potentially erodible material, such as a fine sand or silt, which would tend either to infiltrate the pipe or to be washed out by exfiltration of water from the pipe. The former situation is a particular concern when settled slurry, which forms the foundation for an upstream construction stage, can potentially infiltrate a pipe. When conditions are such that infiltration or exfiltration could affect the safety of the dam, plans should include (even in non-pressure flow designs) a minimum pressure testing requirement. Testing joints to a nominal pressure will provide some assurance that the joints were properly constructed, are soil tight, and will not allow significant leakage.

All installations should be equipped with a pressure gauge and pressure relief valve during the test procedure, and all pressure testing must be conducted in a safe manner. Internal and external temperatures should also be monitored to provide pressure/temperature data in the event calculations become necessary.

E. <u>Conduit Seepage Control Measures</u>

Many public and private dam design and construction groups either permit or install conduits through embankment dams. However, most designers agree that closed hydraulic conveyances should be placed in stronger abutment soils or rock where less settlement and horizontal spreading will occur. Designers have long recognized that pipe installations provide an opportunity for seepage along the conduit. To preclude seepage along the conduit, designers have included impediments such as anti-seepage collars, cutoff walls and collars, and anti-seepage diaphragms. These diaphragms protrude circumferentially from around the conduit into the surrounding dam embankment material. The purpose of such protrusions is to increase the length of the potential seepage path along the pipe from the inlet to the outlet by a specific amount. This reduces the hydraulic gradient at the exit. The lowering of the hydraulic gradient reduces internal erosion or piping potential next to the conduit. The required extension of the seepage path evolved empirically over the past 80 years or so. After many years of trial and error, an increase of 15 to 20 percent is accepted as reasonable and prudent. Bureau of Reclamation engineers using the weighted-creep method of design commonly used percolation path increases on the order of 20 to 30 percent through the inclusion of projecting fins or collars.

The increased percolation path concept was standard practice industry-wide prior to about 1965. Since the late 1960s, an increasing number of practitioners have advocated the use of drains and filters to control the expected seepage along pipes for a variety of reasons. It was not until the early to mid-1980s that large Federal dam design agencies such as the Corps of Engineers, Bureau of Reclamation, and the Soil Conservation Service altered their standard specifications to preclude the use of anti-seepage collars and require inclusion of graded granular filters and drains.

Many of the design applications submitted to MSHA have included provisions for the construction of conduits with anti-seepage diaphragms. Some designs have included drain and filter systems. Materials for the anti-seepage collars have included concrete, steel, and polyethylene. The granular diaphragm material generally conforms to gradations specified in C-33 of the American Standards for Testing of Materials (ASTM). MSHA will accept either method or design philosophy. All design submittals should address conduit seepage control measures.

Dam designers submitting specification drawings and supporting documentation to the agency, are advised to examine appropriate reference lists. One must be cognizant that the construction of pipes with anti-seepage collars is labor intensive and that additional testing and inspection may be required. Also, designers and plan reviewers should direct particular attention to connection details in order to preclude seepage, diaphragm location respective to joints, and potential stress concentrations which may harm the conduit. Where a pipe passes through a rigid collar, provisions should be made for relative movement. In flexible pipes, the connection detail must allow for the anticipated pipe deflection while maintaining a watertight connection. Graded granular materials, on the other hand, must meet sizing requirements and be placed at specific well-defined locations under approved density specifications. Granular materials are to be compatible with surrounding soils and must not be contaminated during placement.

F. Probable Maximum Flood (PMF)

Current, prudent engineering practice requires that dams that are located where failure may cause loss of life or severe property damage be designed for the probable maximum flood (PMF). The PMF is defined as the maximum runoff condition resulting from the most severe combination of hydrologic and meteorologic conditions that are considered reasonably possible for the drainage area. It defines the upper limit of expected flooding from meteorologic events.

Components of the PMF that must be determined by the designer for a particular site include the principal storm, the antecedent storm, the subsequent storm, the time and spatial distribution of the rainfall and snowmelt, and the runoff conditions. While there is basic agreement among dam safety authorities on the combination of conditions and events that comprise the PMF, there are significant differences in the individual components that are used. For the antecedent storm, for example, the Soil Conservation Service and the Bureau of Reclamation use the 100-year frequency storm while the Corps of Engineers may use 50 percent of the probable maximum precipitation (PMP). A reasonable set of conditions for the PMF appears to be the following:

1. Antecedent Storm: 100-year, 6-hour, with antecedent moisture condition II (AMC II), occurring within 5 days prior to the principal storm.

2. Principal Storm: Probable maximum precipitation (PMP) of 6-hour duration <u>with AMC III</u>. In cases where a storm of longer duration results in a higher water level in the impoundment, the storm must be extended, up to 72 hours, to the hydrologically most critical duration. The principal storm rainfall increments must be distributed with time so as to produce the most severe condition.

   Recommended procedures for determining critical rainfall time distribution for areas east of the 103rd meridian are given in Hydrometeorological Report No. 52. The Corps of Engineers computer program HMR52 can be used to compute precipitation values in accordance with these procedures.

   PMP rainfall estimates, for areas east of the 103rd meridian, are given in Hydrometeorological Report No. 51. For the region between the 103rd meridian and the continental divide, probable maximum storms should be developed using the recommended procedures in Hydrometeorological Report No. 55A. For areas west of the Continental Divide, Hydrometeorological Report No. 36, No. 43, or No. 49 should be consulted.

3. Subsequent Storm: In this procedure, a subsequent storm would be considered to be handled by meeting the 10-day drawdown criterion.

As an alternative to using the PMF as defined above, a design that follows the applicable methodology used by a recognized dam safety authority would be acceptable. However, designers are cautioned that storm criteria that are considered acceptable for dams with a properly designed open channel spillway may not be appropriate for dams where the runoff is to be stored. In storage situations, longer duration storms need to be considered.

G. <u>Frequency of Moisture-Density Testing to Verify Compliance with Compaction Specification</u>

Tests need to be performed during the construction of a dam to determine compliance with moisture-density specifications in accordance with the approved plan and to detect any significant changes in the material properties over the construction period. The operator or the operator's agent should have such tests conducted at the following minimum frequencies:

1. One field test for every 2,000 cubic yards of compacted structural fill, with at least one test per lift;

2. one field test for every 200 cubic yards of compacted backfill in trenches or around structures, with at least one test per lift (Note: With small diameter pipes, where the total volume of pipe backfill may be small, more frequent tests than indicated by this criterion should be performed);

3. one test any time there is suspicion of the effectiveness of compaction; and

4. supplementary laboratory compaction curves for at least every 20 field density tests.

Field tests should be performed at random locations in the fill. Records of the test results, as well as the test locations, should be kept at the mine. In cases where a record of consistent test results is established, or in cases involving low-hazard dams, less frequent testing may be considered if justification is provided. Any time there is reason to suspect that the characteristics of the construction material have changed, reasons such as a change in preparation plant processing or unusual compaction test results, the material should be further investigated. Grain-size, compaction, shear-strength, and other tests should be performed as warranted.

H. <u>Use of Geotextiles as a Filter</u>

1. Impoundment plans in which a geotextile is proposed as a filter must include the basis for specifying the particular fabric or fabric characteristics. This should include showing that design criteria with respect to soil retention, permeability, clogging, and constructability have <u>all</u> been considered and met. (Attached references No. 5 and 8 for Chapter 5 are good sources of information on design criteria.) To perform acceptably as a filter in a drainage application, a geotextile must function as follows:

    a. retain the protected soil to prevent piping;

    b. have sufficient permeability to prevent the build-up of water pressure;

    c. not become clogged; and

    d. have sufficient strength to survive the construction procedures.

2. Impoundment plans also should require that critical geotextile installations be observed by a representative of the designer who is knowledgeable about geotextiles and filter requirements and familiar with the placement procedures specified in the plan. In high hazard dams where problems with the filter could lead to failure of the dam, the following are necessary:

    a. the evaluation of clogging potential needs to include a soil-fabric interaction test, and

    b. a sufficient number of piezometers need to be included in the design to allow the drain's performance to be monitored.

    Designers and plan reviewers are cautioned that testing performed by the U.S. Bureau of Mines, although inconclusive, indicated a potential for plugging of the fabric when used as a filter in a coal waste embankment. Concerns for the formation of a precipitate, or the growth of bacteria on the cloth, have been raised. Because of the potential for clogging, filter fabric cloth should be selected with the largest opening size that provides the maximum flow capacity while maintaining the soil retention requirements.

    A high percentage of the problems that have occurred with filter fabric installations has been attributed to incorrect or poor construction procedures. This is why all critical installations need to be observed by a representative of the designer who is knowledgeable about the important function that the geotextile serves.

3. Special attention needs to be given to preventing damage or disturbance of the fabric during installation. The recommendations of Task Force No. 25, which are cited in Geotextile Engineering Manual (see Reference No. 8 of Chapter 5), should be consulted, although they are not intended to replace site-specific evaluation, testing, and design. In general, the manufacturer's recommendations for installation should be followed. Particular attention should be given to the following items.

    a. Fabrics should be secured by sewing, pins, staples, or weights as necessary to prevent disturbance by construction operations or wind. Where seams are to be formed by overlapping, the overlap should be at least 2 to 3 feet and the specific conditions should be evaluated to ensure that the fabric will not open up under load.

    b. In preparing surfaces for fabric placement, depressions, holes, and voids should be filled so that the fabric will not have to bridge them and possibly be torn when cover material is placed. Fabric should not be placed over sharp or angular rocks that could tear or puncture it. An intermediate layer of compatible finer material should be placed over such rocks to protect the fabric.

c. In placing material or using equipment on a fabric, care must be taken to avoid punctures or tears. Fabrics must be specified that have adequate puncture and burst strength for the conditions and construction procedures that will be encountered. Where applicable, specifications should limit the size of rock to be placed on the fabric and the drop height. Generally, stones greater than 250 pounds should be placed with no free-fall. Field trials should be made to ensure that no damage will occur due to the construction procedures. Depending on site conditions, a cushion layer of finer material may be required to protect the fabric.

I. Design of Pipes for External Loading

When a pipe is to be installed under or through a dam, plans must demonstrate through analyses and calculations that adequate factors of safety are provided against the various potential structural failure modes. Potential structural failures include wall crushing, wall buckling, and excessive deflection or wall strain. Parameters used in the various analyses must be adequately substantiated in the submitted plan.

The recommendations contained in the literature of pipe manufacturers, such as tables for the allowable cover over a pipe, must be used with caution. When using such design aids, appropriate assurance for the parameters used in their development should be taken into account for each potential failure mode. For dams with high hazard potential, manufacturers' tables should generally be used for preliminary design purposes only. Detailed analyses and calculations should be included in the plan.

Designers and plan reviewers should note that technical literature contains some significant differences of opinion on the best structural design for flexible pipes. Particular points of contention concern the calculation of deflection and values of the soil modulus or the soil/pipe interaction modulus. For these reasons, the applicability of a manufacturer's recommended design procedure needs to be verified for the particular conditions found at a site. This is especially true for deep burial situations, as the emphasis for most pipe products has been on relatively shallow cover conditions, such as sewer installations. Until performance data is established for high cover situations, conservative design methods need to be used. Factors of safety of at least 2.0 should be specified. Where applicable, deflections should be checked using the Iowa Formula, with conservative values for the modulus of soil reaction. Because of the limitations of traditional, empirical design methods, use of a finite element analysis, such as the CANDE-89 program, is now considered by some to represent the best available method of design. For flexible pipes, in addition to the deflection caused by fill loading, installation deflection also needs to be taken into account in determining whether total deflection will be within acceptable limits.

Consideration should be given to limiting fill height by installing new pipes at higher elevations and grouting deeply buried pipes.

In high fill applications, due to uncertainty about pipe/soil interaction and the lack of performance data, the performance of the pipe may need to be verified by a monitoring device such as a deflectometer, a "go, no-go" device, or a TV camera. Also, contingency measures to repair or replace the pipe may be required in the event that monitoring shows that structural performance limits are exceeded.

The "imperfect ditch" or "induced trench" method of pipe installation should not be used in dams due to the potential for creating a seepage path and the uncertainty of the arching action under saturated conditions.

J. Phreatic Surface

All design plans submitted for MSHA approval must include minimum slope stability factors of safety as required by 30 CFR 77.216-2(a)(13) before approval will be granted. An integral part of any slope stability analysis is the phreatic surface that is assumed to be present. The assumed phreatic surface used in the stability analysis should be either conservatively depicted or substantiated with appropriate seepage analyses.

Piezometers should be used in embankments to monitor the phreatic surface so potential instability problems can be quickly identified. However, piezometers by themselves should not be used to determine if the phreatic surface used in the design process is acceptable. The seepage analysis should be used in the design process to determine the maximum anticipated phreatic surface. The piezometers are then used to monitor the phreatic surface during the life of the embankment and verify the phreatic surface used in the design. If piezometer readings above the phreatic surface used in the stability analysis are obtained and appear to be accurate, then the stability of the embankment should be reassessed using the higher phreatic surface.

The long-term stability analysis for each stage should be based on a phreatic surface in the embankment which is at or above the anticipated phreatic surface for the long-term steady-state seepage condition. The designer may choose to determine the phreatic surface which results in the minimum acceptable stability factors of safety. A seepage analysis should then be provided to indicate that the maximum anticipated phreatic surface is below the phreatic surface used to obtain the minimum acceptable stability factors of safety. The long-term, steady-state seepage condition should be determined by assuming the pool water surface elevation at the lowest ungated water outlet. This is usually the invert elevation of the lowest ungated principal spillway or, if an ungated principal spillway is not provided, the invert elevation of the lowest open channel spillway. The fine refuse beach formed on the upstream face of most coal refuse embankments is conservatively assumed to present no hydraulic head loss in the seepage analysis, due primarily to inherent uncertainties in determining its degree of consolidation, density, gradation, and coefficient of permeability.

Where applicable, the phreatic surface for a rapid reservoir drawdown condition should be evaluated for use in the rapid drawdown condition stability analysis. In many instances, the phreatic surface for the rapid reservoir drawdown condition will not be appreciably higher than the phreatic surface for the long-term steady-state seepage condition because the higher phreatic surface usually does not have sufficient time to fully develop or the upstream embankment soil is relatively free draining. Cedergren (Reference 6 for this Chapter) provides a quick method for estimating the phreatic surface for drawdown conditions.

Many different methods are currently available for estimating the maximum anticipated phreatic surface for steady-state conditions within an embankment. The Corps of Engineers, Seepage Analysis and Control for Dams, EM-1110-2-1901 (Reference 9 for this Chapter) provides an excellent summary of the available methods. Practically all methods are based on the LaPlace equations and Darcy's law of laminar flow through porous media. The complexity of the embankment in terms of permeability and anisotropic conditions, and the familiarity of the designer with a specific method usually dictates which method is used. Perhaps the most common methods are the flow net construction methods presented by Casagrande (Reference 5 for this Chapter), Corps of Engineers (Reference 9 for this Chapter), Cedergren (Reference 6 for this Chapter), and the computerized finite element methods. The finite element methods are becoming increasingly more popular and are particularly useful for evaluating the effects of different conditions. However, with each method, extreme care must be exercised to ensure that the assumptions inherent in the method and procedures are fully satisfied or do not significantly affect the results.

The coefficients of permeability used in the seepage analysis should be either conservatively chosen or should be determined by using laboratory permeability tests (References 1, 4, 7 for this Chapter) or field permeability tests (References 3, 4, 6, 9 for this Chapter). The obtained coefficients of permeability are generally regarded as accurate to only one order of magnitude. This accuracy should be kept in mind for all seepage analyses.

It is well documented that compacted embankments usually demonstrate a coefficient of permeability in the horizontal direction which is greater than the coefficient of permeability in the vertical direction. A term called the "permeability ratio" is commonly used to express the horizontal coefficient of permeability to the vertical coefficient of permeability. The available literature shows a wide range of permeability ratios, from less than 1 to over 100, for earthen embankments. MSHA has examined the guidelines of other recognized agencies experienced in dam design and construction, most notably the Corps of Engineers (Reference 8) and the Bureau of Reclamation (Reference 3 for this Chapter) and other published permeability ratios, and has concluded that all embankment plans should be designed assuming a minimum permeability ratio of 9. Although the published information supports this ratio, lower permeability ratios may be allowed provided they are adequately substantiated and documented.

Many types of drains are commonly incorporated in embankments to lower the phreatic surface, control internal seepage, and help stabilize the embankment. These drains must be designed for material compatibility and relative permeability with respect to surrounding soils as explained in Section B, Graded Filters, and in Section H, Geotextiles as a Filter, to prevent piping yet provide adequate drainage capacity. Any drains used in the seepage analysis to determine the maximum anticipated phreatic surface should have calculations substantiating their capacity to carry at least 10 times the anticipated seepage flow. This drain capacity factor of safety is needed because of the potential inaccuracy of the coefficients of permeability and potential inadequacies in proper placement of the drain. A drain capacity factor of safety above 10 may even be warranted for conditions involving semi-turbulent and turbulent flow conditions. The Corps of Engineers (Reference 9 for this Chapter), Cedergren (Reference 6 for this Chapter), and Leps (Reference 10 for this Chapter) provide information for determining flow rates for semi-turbulent and turbulent flow conditions where Darcy's law is invalid. Drains should be a size that will ensure that the phreatic surface is directed into the drain instead of over it. The drains should have adequate thickness, usually at least 3 feet, and the material be properly placed to prevent segregation.

K. Special Considerations for Short-Term Conditions

Coal waste disposal operations that are of sufficient size to fall within MSHA design criteria are best described as being in a constantly changing mode. The availability of embankment building material is generally dependent upon the rate of coal production and the percentage of waste material present in the mine's production. Mine waste impounding structures will grow quickly during periods of high mine production, such as those due to favorable market conditions, and remain stagnant during low mine production periods, such as those due to unfavorable market conditions, unless other types of embankment material are utilized. This is contrary to typical dam construction activity. When an impounding facility is built by other agencies or private industry, construction is usually continuous until completion of the facility. The operator of a refuse disposal facility should recognize that MSHA may require that a refuse dam be completed with other materials to maintain the operational safety of the structure.

The mining industry is confronted with conditions that are unique to waste disposal operations. In light of these conditions, MSHA will consider accepting a design storm of less magnitude than the full design storm during unavoidable short-term construction periods. Unavoidable refers to periods of time when application of the full design storm criteria in the design of the structure is virtually impossible. These periods are normally associated with initial start-up conditions and abandonment. Normally, short-term criteria only apply during the first 2 years after the initial start-up of the facility and within 2 years from the final abandonment of the site. There can be other times where unavoidable circumstances occur, but these circumstances should be very short-term. A smaller storm should never be used in the design just for convenience or to reduce the final cost of the structure.

A maximum time of 2 years is considered adequate for a mining company to resolve any conditions that would prevent the implementation of long-term criteria. This does not mean that in every case a full 2 year delay in implementation is appropriate. Generally, the timeframe will be much less than 2 years. It should always be kept to the lowest timeframe reasonably possible. With proper planning and diligent effort, most delays can be completely eliminated. Some examples of short-term conditions are as follows.

1. Short-term conditions may be necessary during initial construction of a new impounding structure. During this time, the embankment height is being raised to the design height to provide the necessary storage, surcharge, and freeboard to control the design storm. For coal refuse facilities, this time should not exceed a period of 6 months to 1 year.

2. In conditions where the company is changing from an open channel spillway to a storage type configuration, there could be a time period where the full design storm cannot be passed. This time must be as short as possible, and a very positive plan for the sequence of change must be provided.

3. During the period that an operating impounding facility is being changed to a non-impounding facility, the company must eliminate the available storage and/or surcharge by excavating the spillway deeper or by filling the impoundment with coarse refuse.

L. Effects of Mining on Dams and Impoundments

In designing a dam, an important factor to be considered is the location of present, and possible future, underground mining near the proposed site. One of the requirements for a safe dam is that deformations be minimized so that cracking of the dam is eliminated and an adequate freeboard is maintained. Another requirement is that seepage through a dam and its foundation be minimized and controlled. Mine subsidence and mining-induced strains can jeopardize these dam safety requirements.

When mine subsidence occurs, tensile strains are induced and zones of tension are created at the surface. As a result, cracks can occur in soils and mine waste materials because such materials have low resistance to tensile stress. Openings can occur in the foundation rock due to cracks or when tensile strains become concentrated along existing joints. Conduits that pass through a dam can be pulled apart or otherwise damaged by differential movements.

A crack in a dam, an open rock joint in its foundation, or a damaged conduit can result in piping due to the concentration of seepage in that area. Piping is a process of internal erosion where the amount of seepage progressively increases as more and more material is carried away with the flow. This process can lead to the eventual failure of the dam. A prime example of this is the Teton Dam failure in Idaho in 1976. Piping can occur through the foundation soil or through the dam itself. The embankment or foundation materials may be carried into and through openings in the rock foundation. Piping can also occur along or in damaged conduits. Over 30 percent of all dam failures occur due to seepage or piping problems.

Differential movements resulting from subsidence can cause other problems by affecting the function of internal design features such as filters and drains. These problems can result in higher pore water pressures than the dam was designed for and can cause slope failure. Subsidence also can reduce the amount of freeboard, and could result in the dam being overtopped during a storm.

For these reasons, a site that has been undermined or under which mining is planned may not be suitable for the construction of a dam. Designers should be sure to investigate alternative sites. Where use of an undermined site must be proposed, designers should realize that a more comprehensive foundation investigation is called for, that extensive remedial measures may be required to make the site acceptable, and that additional safety features are normally required in the dam's design.

1. Establishment of "Safety Zone"

The most prudent and recommended design approach is to locate dams far enough from mining that they will not be affected by subsidence. To do this, the area of mining influence should be delineated. One method of doing this is to determine a draw angle. This establishes a "safety zone" beneath and around the dam. No mining is permitted within this zone. The extent of the "safety zone" should be conservatively estimated, based on the specific site conditions and local experience, and considering that tensile strains as low as .1% - .3% are sufficient to cause cracks in some earthen materials.

All information used in determining how close to the dam the mining can safely occur, or the location of the "safety zone," needs to be fully documented in the impoundment plan submitted to MSHA for approval. Substantiation should include detailed geologic sections and mine maps. The analysis of the subsidence potential should take into account local subsidence experience and local conditions and needs to include the technical basis for the proposed extent of the safety zone.

The information contained in References No. 1 and 3 of this Chapter should be consulted for information concerning "safety zones."

2. Uncertainties of Subsidence Effects

The problem in dealing with undermined sites is the difficulty in determining how subsidence has affected the foundation and in predicting how it will affect the dam. The effect that underground mining has on the surface depends primarily on the type of mining, the percent extraction, and the amount and type of overburden. In room and pillar mining (first mining only), with adequately sized pillars and with competent roof and floor rock, there may be no significant impact at the surface. However, the surface may be affected if the pillars are too small, if they deteriorate with time, or if the floor is too weak and becomes soft due to moisture, resulting in the pillars punching into it. At shallow depths, sinkholes can extend to the surface regardless of pillar size if entries are driven too wide. Full extraction mining methods will affect the surface in virtually all cases, with the surface strains generally increasing as the mining depth decreases.

With full extraction methods, uncertainty stems from the inability to predict and determine the tensile strain distribution at and near the surface. In room and pillar mining, there is the unknown long-term behavior of the roof/pillar/floor structural unit. In both cases, methods are lacking to establish the response of the dam and foundation materials to the potential strains or movements. Determining the true extent of disturbance to the foundation, and how it will behave under full reservoir head, is difficult even with an extensive foundation testing program. For these reasons, a thorough consideration of alternative sites should be made.

3. <u>Design Features to Compensate for Mining Effects</u>

If there are no alternatives, and a dam is proposed on a site that is already undermined, then a comprehensive foundation investigation is called for. Specific features must be incorporated into the dam's design to allow it to safely withstand any potential effects of the mining.

Design measures that should be considered in such cases include but are not limited to the following:

a. conducting a more extensive foundation investigation to locate openings and zones of high permeability;

b. taking special precautions during foundation preparation to ensure that any open joints or cracks in rock foundations are adequately sealed off, such as by grouting, or that a protective filter zone is provided;

c. backfilling or grouting the mine openings in critical support areas to minimize or reduce the amount of movement which can occur;

d. specifying a very wide dam cross-section and crest width to provide increased mass and greater resistance to piping failure;

e. maintaining an ample amount of freeboard to compensate for the maximum likely subsidence;

f. specifying larger drain and filter cross-sections, so that these internal features would continue to be functional with the maximum likely subsidence;

g. locating any decant pipes over unmined or backfilled areas;

h. compacting materials at water contents slightly wet of optimum to increase their ability to deform without cracking;

i. incorporating design features, such as a grout curtain and impermeable embankment zone, to minimize the amount of seepage through the dam and its foundation;

j. incorporating design features, such as a chimney drain, to collect seepage and discharge it in a controlled manner;

k. using wide zones of materials with "self-healing" characteristics, to act as crack stoppers; and

l. specifying a comprehensive monitoring program for the dam to provide for the early indication of a potential problem.

Proposed safety measures must be fully documented in the plan that is submitted to MSHA for approval. Plans should include detailed geologic information, mine maps showing present mine layout and mining projections, an evaluation of pillar and floor stability, analyses of subsidence and sinkhole potential, and an evaluation of the cracking and piping potential of the embankment and foundation materials. The subsidence analysis should describe all existing and anticipated movements and strains, how they were evaluated, and what specific design measures were incorporated to compensate for present and potential subsidence effects.

In general, a designer should include redundancy in the design so that the disruption or failure of any one feature would not jeopardize the safety of the dam. Required features must be selected and evaluated on a case-by-case basis depending on specific site conditions, especially the hazard potential. Plans that involve undermining and that are submitted without conservative defensive measures, or without an adequate justification based on an appropriate level of testing and technical analyses, should not be approved.

4. Pillar/Floor/Roof Evaluations

The stability of the roof, pillars, and floor must be evaluated in cases where a dam is proposed over existing room and pillar mining, and in cases where a limited number of entries might be proposed under a dam. Analyses must show that pillars have a conservative factor of safety with respect to crushing. The factor of safety should be greater than 2.0 for the long-term support of critical areas. Since different methods of evaluating pillar strength can indicate a significant variation in safety factors, consideration of several methods is suggested and the use of a conservative method is called for. Where existing pillars are found to be inadequate, additional support, such as by grouting, needs to be provided. If the area is accessible, the possibility of providing support from underground should be considered.

The potential for subsidence due to pillars punching into the floor needs to be analyzed. In this regard, experience in the mine and the potential for softening of the floor due to moisture must be evaluated. Where the cover is shallow, the potential for sinkhole development also must be analyzed and accounted for in the design. In any of these analyses, the engineering properties of the coal and rock need to be determined by testing.

5. Mining Near Existing Dams

After a dam has been constructed, any mining that is to occur near it must be carefully planned. Due to the uncertainty of long-term support, the development of entries near or under dams needs to be avoided. Only under favorable conditions and where entry development is essential for ventilation or haulage safety should limited mining be considered under an existing dam.

Since full extracting mining methods, e.g., longwall mining and pillar extraction, affect the surface in virtually all cases, such mining is normally not acceptable either under a dam, or within a zone of influence of the dam.

6. Auger Holes or Mine Openings in Abutment

Where mine openings or auger holes occur in an abutment, plans need to include analyses showing that potential problems due to deformation and seepage have been accounted for in the design. In such cases, plans normally include provisions to provide support by backfilling the openings, and to control seepage by the placement of filters and drains along the openings.

7. Monitoring

In any case where mining induced deformations could have an adverse effect on the dam, the performance of the dam should be monitored. The monitoring of horizontal and vertical movements, piezometric levels, and seepage quantity is normally required.

8. Effects on the Mine

The possibility of a hazard to underground miners due to an inrush of water or slurry into the mine is another concern whenever there is mining near an impoundment. Plans should include a complete evaluation of this potential, including such items as:

a. The potential for an inrush into the mine due to sinkhole development;

b. the likelihood of increased mine water inflow due to higher overburden permeability;

c. the possibility of inflow due to disturbances along geologic discontinuities;

d. the potential inflow rates and volumes;

e. the possible flow paths and water depths within the mine;

f. the effects of inflow on mine ventilation and escapeways; and

g. the measures to be taken underground to handle inflow.

Regulations pertaining to mining under bodies of water are contained in 30 CFR 75.1716 through 75.1717. These regulations should be consulted prior to the commencement of such mining operations.

M. Erosion Protection for Spillways

The integrity of open channel emergency spillways during a storm event must be ensured. Topographic constraints in the mining industry often necessitate that open channel spillways be placed immediately adjacent to or on the impounding structure. A failure of the spillway in this location could jeopardize the entire facility. The serious consequences of failure dictate that the same rationale used in the selection of the design storm event must apply to the design criteria for emergency spillways.

The preferred design of an open channel is to cut it through competent rock. When this is not possible, the design and construction of spillway linings for erosion protection must be accomplished in a manner that will ensure the maximum protection of the lining against the forces resulting from the peak design flow velocity.

Riprap has been used as channel lining material; however, its stability under high velocities is a serious concern. The various design methods that are available will yield a wide range of required rock sizes for a given set of conditions. These inconsistencies raise questions as to the application of those methods to the design of emergency spillway linings. Most riprap design methods were developed by Federal and State agencies for particular public works projects. Typical projects that might use riprap protection include highway embankments, bridge abutments, flood channels, canals, and stilling basins. The type of project to be protected and the experience of each agency greatly influence the design method chosen. The failure of the riprap protection in these projects generally will not create a life-threatening situation. The failure of riprap lining in an emergency spillway could cause the breach of an impounding facility resulting in death and significant property damage. Therefore, the use of riprap in emergency spillways subjected to high velocities is strongly discouraged, unless special considerations are addressed. Plans proposing riprap must include calculations to support the proposed stone sizes. Riprap specifications should address stone gradation, layer thickness, bedding requirements, and stone durability.

Gabions, which consist of wire baskets filled with rock, are considered by many to solve some of the problems related to the use of riprap. Properly designed, the wire mesh can successfully contain a much smaller-sized rock when exposed to high velocity flow. This type of system has the limited ability to change shape without failure when unstable ground conditions occur. The problems associated with some of the hydraulic forces are eliminated because gabions are permeable.

Rigid linings are a potential solution to the limitations associated with the use of riprap or gabions. The list of rigid linings includes grouted riprap, concrete, and formed concrete products such as Armorform or Fabriform. Many rigid linings are destroyed due to flow undercutting the lining, channel headcuttings, or hydrostatic pressure behind the channel walls or floor. If a section of a rigid lining fails, then the remaining sections could fail in a rapid succession. Positive under-seepage cutoffs and weep holes are design measures that should therefore be used.

Formed concrete products are seeing application as spillway linings under certain conditions. Non-reinforced cement grout bags must be treated as rigid linings. As rigid linings, these systems present some concerns due to a lean concrete mix, a lack of aggregate in the mix, and an absence of embedded steel reinforcement. Also, the bag will deteriorate over time, allowing the cracked sections to move freely and independently. Recent advances have been made in increasing the strength and stability of uniform sections and articulated products. Steel or plastic fibers can be mixed with the cement grout to provide an increase in tensile and bending strength. Transverse and longitudinal cables of steel or nylon can be inserted to prevent excessive movement and separation.

Linings consisting of synthetic grass-reinforcement materials have been successfully used in some low hazard outlets and diversion channels where the anticipated velocities are low and loss of the structure would not be expected. These products are still considered experimental and their use should be limited to low hazard facilities on a site-by-site basis.

The selection of the type of lining is critical to the overall facility design. Seeking design support from the manufacturer in making this decision is important. Manufacturers should be made thoroughly aware of the intended use of the product and the consequence of system failure.

The loss of lining protection cannot be allowed in an emergency spillway. Several concerns must be thoroughly addressed if such a protection system is being considered. The foundation is of primary importance. Erodible materials must be protected from the forces of high velocity flow. The design should include comprehensive foundation preparation and an appropriate base, which might include a geotextile and an underfilter. Additionally, the integrity of the lining material must be ensured. Damage is most likely during peak design storm conditions when the outflow is highest and maintenance access is unlikely. The impact of debris impingement and the resulting displacements must be considered. It is, therefore, critical that a positive means of lining protection or anchorage be developed. Systems that could satisfy this criteria might include an anchored wire mesh or grouted rock bolts to minimize movement and a float device that would prevent debris from entering the spillway.

Regardless of the type of lining selected, a hydraulic analysis is needed to determine the maximum flow depths and velocities, the duration of such flows, and a complete water surface profile. This information will be used to determine the magnitude of the forces (e.g., hydrodynamic lift and drag, tractive and critical shear stress) that the particular lining will be exposed to. The plan submitted to MSHA should include a complete technical analysis demonstrating that the proposed lining is capable of withstanding these forces. The plan also must include detailed specifications on liner material and placement.

A significant consideration with any spillway, whether cut into rock or lined, is periodic examination. Exposure to the elements will cause deterioration to occur and, thus, evaluation of its extent and potential impact on performance is critical. Impoundment plans should include specific provisions addressing this concern.

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APPENDIX A

Summary Outline

The main items to be covered during an inspection, as discussed in Chapter 4, are summarized here. When they appear potentially significant, or when noticeable changes are observed from one inspection to the next, the inspector should describe the location and condition of any of these items on the Periodic Inspection Form.

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GENERAL SITE CONDITIONS

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DOWNSTREAM CONDITIONS

Inspection Concerns
* Comparison of existing development with approved plan
* New development (planned or built) that might be affected by a failure

Items to be recorded
* Status of change: planned, underway, completed
* Location and description of change

WATERSHED CONDITIONS

Inspection Concerns
* Comparison of existing conditions with approved plan
* Changes in the watershed that could increase flood flows

Items to be recorded
* Status of change: planned, underway, completed
* Location and description of change

STREAM CHARACTERISTICS

Inspection Concerns
* Unusual buildup of sediment
* Discoloration of stream

Items to be recorded
* Any changes in stream characteristics

****

CONSTRUCTION AND SITE CONDITIONS

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FOUNDATION PREPARATION

Inspection Concerns

* Vegetation removal in all areas
* Special preparation in critical areas

Items to be recorded

* Locations and conditions where preparation appears inadequate

PLACEMENT OF MATERIALS

Inspection Concerns

* Comparison of disposal procedures with approved plan requirements
* Noticeable changes from past procedures
* Proper compaction practices for embankment fill
* Placement of improper materials within the fill
* Proper pipe installation procedures
* Proper filter and drain installation practices

Items to be recorded

* Description and location of practices that deviate from the approved plan
* Description of a noticeable change in operations
* Description of poor compaction practices
* Types of improper material being placed and its location and
* Description of any problems with pipe, filter or drain installations

ROAD CONSTRUCTION

Inspection Concerns

* Road excavation into a slope that could cause instability
* Local road conditions that could threaten the safety of operators
* Road construction that blocks or changes drainage conditions

Items to be recorded

* Location and description of any potentially hazardous condition

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EMBANKMENT SLOPES
****

STEEPNESS

Items to be recorded
* Location of any areas where the slope appears abnormally steep

SEEPAGE FROM SLOPES

Inspection Concerns
* Flow from underdrain pipes
* Seepage at isolated points
* Seepage along outside of decant or spillway pipes
* Seepage at the abutment
* Seepage over large area
* Changes in any of these conditions

Important Indicators
* Flowing water on the slope
* Wet or soft areas on slope
* Areas of lush vegetation
* Areas of dead vegetation
* Areas where snow melts more rapidly than elsewhere
* Areas with unusual ice buildup

Items to be recorded
* Seepage location and any observed changes
* Approximate increase or decrease in flow
* Water discoloration

SLOPE MOVEMENTS

Inspection Concerns
* Cracks on the crest
* Cracks on the slope
* Bulging on the slope or at the toe
* Signs of shallow surface movement

Important Indicators
* Observed cracks or bulges
* Relationship between bulging and cracks
* Relationship between movement and seepage zones
* Relationship between movement and oversteepened or eroded areas

Items to be recorded
* Location of cracks and bulges
* Length and opening size of cracks
* Vertical displacement across crack
* Height and approximate size of bulge

SLOPE EROSION

Inspection Concerns
* Significant erosion gullies on slope or at abutment or toe

Items to be recorded
* Erosion location and extent
* Depth and width of erosion gullies
* Source of water causing erosion (seepage and/or runoff)
* Sloughing is occurring along the gully

****

DOWNSTREAM FOUNDATION CONDITIONS

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SEEPAGE FROM FOUNDATION

Inspection Concerns
* Seepage at isolated points
* Seepage where the slope meets the natural hillside
* Seepage over large areas
* Seepage carrying fines
* "Boils" in the bottom of streams or in ponded areas

Important Indicators
* Flowing water
* Wet or soft areas
* Areas of lush vegetation
* Areas of dead vegetation
* Areas where snow melts rapidly
* Areas with ice buildup

Items to be recorded
* Seepage location and whether changes occur
* Approximate increase or decrease in flow
* Water discoloration

MOVEMENT IN DOWNSTREAM FOUNDATION AREA

Inspection Concerns
* Horizontal movement away from the slope
* Bulging of the downstream foundation materials
* Any movement on natural hillsides
* Relationships between movement and cracks/seepage/erosion

Important Indicators
* Simple observations of bulging or ridges
* Unusual tilting of trees or other vegetation

Items to be recorded
* Location and description of movement
* Height of bulging

EROSION IN DOWNSTREAM AREA

Inspection Concerns
* Erosion gullies at the natural hillside
* Erosion at the discharge end of drainage facilities

Items to be recorded
* Locations of erosion
* Depth and width of erosion gullies
* Source of water causing the erosion
* Sloughing is occurring

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SLURRY IMPOUNDMENTS

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WATER LEVEL

Inspection Concerns
* Abnormal increase in water level without heavy rainfall
* An abnormally long period of high water after a storm
* An unusual decrease in the water level

Items to be recorded
* Approximate rise or fall in water level
* Any clogging of decant
* Any efforts by the owner to remedy decant clogging

EMBANKMENT FREEBOARD

Inspection Concerns
* Comparison of actual freeboard condition with approved plan requirement

Items to be recorded
* Approximate freeboard if it appears to be less than required

SLURRY DISCHARGE LOCATION

Inspection Concerns
* Discharge pipe location
* Any erosion at discharge

Items to be recorded
* Discharge location if not at the upstream embankment slope, or as specified
* Erosion at the discharge, if any

UPSTREAM EMBANKMENT CONDITIONS

Inspection Concerns
* Steepness of slope
* Cracks on the crest or slope
* Bulging on the slope
* Erosion of the upstream slope

Important Indicators
* Visible cracks and/or bulges
* Any relationship between cracks, bulges and/or erosion

Items to be recorded
* Location of cracks and bulges
* Length, amount of opening, vertical displacement of cracks
* Height of bulges

IMPOUNDMENT AREA SURFACE

Items to be recorded
* Location and description of "sinkholes" or unusual depressions on the settled fine refuse surface

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DRAINAGE FACILITIES

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SPILLWAY CHANNELS AND PIPES

Inspection Concerns
* Obstruction by vegetation or debris
* Obstruction by sloughing or sliding of slopes
* Erosion of channel or side slopes
* Condition at discharge end
* Deterioration of erosion protection or lining
* Crushing or cracking of pipes
* Corrosion of pipe

Items to be recorded
* Location and cause of clogging
* Potential for additional clogging
* Description and location of any erosion
* Description of any concrete or riprap deterioration
* Any pipe damage

DECANT SYSTEMS

Inspection Concerns
* Clogging of inlet or pipe
* Corrosion or damage of trash rack
* Cracking, crushing or corrosion of pipe
* Condition at discharge end
* Deterioration of concrete or riprap

Items to be recorded
* Cause of clogging
* Frequency of clogging
* Description of any damage at intake
* Any pipe damage
* Description and location of erosion
* Description of any concrete or riprap deterioration

PUMPS

Inspection Items
* General appearance of pump, and condition of power source
* Location and condition of discharge point
* Observation of operation, if questionable

Items to be recorded
* Any apparent maintenance deficiencies
* Any undesireable conditions at the discharge point
* Any known difficulties with pump operation

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INSTRUMENTATION

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PIEZOMETERS

Inspection Concerns
* Conditions which allow surface water to enter borehole
* Damage to piezometer pipe due to equipment or construction activity
* Absent or damaged protective housing or markings
* Missing pipe cap

Items to be recorded
* Extent and cause of damage
* Any need for additional protective measures

WEIRS

Inspection Concerns
* Damage due to equipment or construction activity
* Malfunctioning due to erosion under or around the weir, obstructions, or sedimentation

Items to be recorded
* Extent and cause of damage or malfunction

SURVEY MONUMENTS

Inspection Concerns
* Obvious disturbance due to equipment operation, construction activity, or natural causes such as slides, erosion or frost heave
* Potential or imminent displacement due to any of the above

Items to be recorded
* Extent, location and suspected cause of displacement, potential displacement, or damage

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ADDITIONAL CONSIDERATIONS

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BURNING

Inspection Concerns
* Construction procedures that could increase burning potential
* Changes in the appearance or extent of burning areas
* Refuse being placed over a burning area
* Compliance with extinguishment procedures approved by MSHA

Items to be recorded
* Description of any changes in burning areas

APPENDIX B

Description of Forms

A. PURPOSE OF THE PERIODIC INSPECTION FORMS

The Periodic Inspection Forms are basic reporting instruments for coal refuse facility inspections. They are essentially a checklist of critical inspection items for a refuse pile or an impounding structure.

The purpose of the form(s) is to maximize the use of the inspector's field time by providing a guide, and to communicate observations to the appropriate district personnel or to MSHA's Technical Support.

B. USE OF FORMS

The form(s) requests certain information to properly identify the structure. It is imperative that this information is correct in order to facilitate any follow-up site visits by the district specialist.

Included at the top of each form are spaces for the Refuse Facility Identification number assigned by the MSHA district office, and the Field Hazard Classification (FHC) assigned by the inspector or specialist after the plan has been reviewed and the site was initially visited. The inspector must use the correct identification number, and should fill out the FHC as it is shown on the approved plan. If there are any questions concerning the assigned FHC due to the potential downstream consequences, the inspector should note this concern on the form.

The remainder of the form(s) is for recording actual inspection observations of adverse conditions and changes. The location of these problems should be noted and sketched in a plan-view and should include such critical stability items as slides, seeps, erosion, cracks or slumps, etc. This information should then be submitted and brought to the attention of the appropriate district personnel for further evaluation.

C. EXAMPLES OF A COMPLETED INSPECTION FORM

Exhibits 1 and 2 contain completed examples of typical recording responses. A sketch of the site has been included on the back of the form(s) and comments have been added where appropriate. It should be noted when information is not available or discernable, and other categories should be marked N/A if the item is not applicable.

APPENDIX C

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